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A TECHNICAL STUDY

DOCUMENTS

# FRANCISCO INTERNATIONAL AIRPORT

INCORPORATED
OF THE

AFA

IATION FACILITIES ASSOCIATES INCORPORATED

333.1-8

DOCUMENTS

THIS STUDY, CONDUCTED FOR THE PUBLIC UTILITIES COMMISSION OF THE CITY AND COUNTY OF SAN FRANCISCO, WAS RECOMMENDED BY THE MANAGER OF THE SAN FRANCISCO INTERNATIONAL AIRPORT AS A FUNDAMENTAL STEP IN THE AIRPORT DEVELOPMENT PROGRAM.

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# INTRODUCTION

Like automotive transportation, aviation can progress effectively only as far as the state of its ground facilities permits. Unfortunately, the maintenance and improvement of ground facilities has up to the present been largely divorced from the technical development of the airplane itself. The size and speed of aircraft, the power of the engines used, and the functions and responsibilities of the fledgling industry have all been pushed ahead of the ground facilities upon which they must depend. Airplanes have increased in size and speed beyond the capacities of most existing airports.

The steps being taken by the City and County of San Francisco to bring its airport abreast of present and foreseeable future demand show a commendable initiative. Only through the nationwide exercise of similar foresight can the full potential benefits of aviation be realized.

Until all the country's air navigation and traffic control systems, major air terminals and related ground facilities have been brought up to date, the airlines will be unable to provide absolutely safe, reliable, and efficient public service. And until they can provide such a service, the airlines will be unable to rise above the present plateau in their development. A study recently made by New York airline officials illustrates the importance of this statement. This study, reported in "Aviation Daily", revealed that 35 per cent of the decrease in load factors in the New York area is associated with the unreliability of scheduled air service. It also showed that 90 per cent of all passenger complaints were connected in some way with the undependability of air travel. We must begin to think ahead in airport design and construction. Our communications system is essential to both our national economic health and to our national security.

For some time to come, the nature of terminal facilities will be conditioned by the limitations of the human pilot. Plane size, maneuverability and approach speeds, traffic control methods, and landing aids must all be within the grasp of human physiology and psychology. However, the time of automatic flight control is approaching, and the aids whose immediate installation is essential for use by a human intermediary should also be adapted, where possible, to integration within the "superhuman" flight era which is to come. Some of these aids will be outmoded when that era arrives, but there is certain to be a transition period of considerable length in which both types will be used.

As practiced at the present time, landing and takeoff in instrument weather is accomplished by means of combining information from different sources. Pilots make use of instrument indications and visual indications, together or in sequence, as each is more appropriate or dependable. The usual sequence is: (1) radio range letdown to approach altitudes and position, (2) ILS landing approach, and (3) visual guidance during the terminal and touchdown stages of the landing. The radio range station should always be considered a part of the terminal facilities as well as of the airways control system.

Radio ranges and instrument landing systems, as installed and maintained by the Civil Aeronautics Administration, are excellent and dependable devices for bringing a plane to the threshold of the instrument runway. However the addition of some form of radar for direct observation of airport traffic in bad weather is almost mandatory at busy metropolitan terminals if traffic is to be maintained at a high level with complete safety and efficiency. Rada is also available in forms which permit it to direct approaches on non-instrument runways in case of need, and to monitor ILS approaches for that additional measure of certainty which is always highly desirable.

At present, few airline pilots are sufficiently skilled in ILS to dispense with visual aid during the last 200 feet of descent toward the runway. High intensity approach and runway lighting systems serve the dual purpose of increasing the distance and altitude at which visual guidance is available, and of making such guidance specific and distinctive. Approach terrain at most airports gives only a general, and often a confused, indication of the path along which a pilot should direct his plane.

Fog dispersal is used to artificially produce minimum ceilings and visibilities at will. Where fogs are of frequent occurrence and of long duration, it may be employed to increase the usability of airport facilities. It is not an inexpensive device, however, and must be justified economically by the increase in operations completed which will result from its installation at a particular airport.

None of the aids here discussed can be installed separately with the expectation of setting up an "all-weather" aviation terminal. They must be set up and used as an integrated system of aids, each fulfilling a portion of the total need for guidance. Thus, the ILS will bring a plane safely through a low ceiling, but cannot as yet be used generally for touching down; approach and runway lighting will guide the pilot through the final approach and landing stages, but will not serve to direct a range letdown or the outer approach in any seriously restricted visibility condition. FIDO backs up the effectiveness of lighting devices, assuring unobstructed visibility in dense fogs which cannot be penetrated by the lighting devices.

An airport can "play ball" in any weather only when the full team is on the field.

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SECTION 5. ECONOMIC JUSTIFICATION
SECTION 6. RECOMMENDATIONS
SECTION 7. LAYOUT OF INSTALLATIONS

PREPARED FOR THE CITY AND COUNTY OF SAN FRANCISC

A TECHNICAL STUDY FOR

# N FRANCISCO INTERNATIONAL AIRPORT.

AN ANALYSIS OF THE LOCAL FACTORS INFLUENCING THE SELECTION, INSTALLATION AND USE OF THE LANDING AIDS TO ACHIEVE ALL WEATHER OPERATION.

AVIATION FACILITIES ASSOCIATES INCORPORATED

# METEOROLOGICAL ANALYSIS

## Introduction

In general, weather determines the availability of an airport to receive and dispatch aircraft. It also determines, in the last analysis, what landing aids are essential to uninterrupted aircraft operation. A study of the weather history at the San Francisco Airport will show what conditions must be overcome, their relative predominance, and, by inference, the necessity for each of the various types of landing aids.

Weather throughout the world follows a number of cycles, the effects of which are superimposed; that is, each is influencing the conditions at any given time. In addition to the familiar daily and annual variations, there have been identified long-term weather cycles having periods of 7 1/2 years, 22 years, and 68 years. However, none of the cycles is exactly repetitive; the maximums and minimums in any area of measurement occur at slightly different times and have lower or higher absolute values in subsequent cycles. Variations of a particular weather condition may, at any one spot, and for any given point in a weather cycle, produce atypical weather conditions. Nevertheless, the same kind of weather recurs in the same general period of each weather cycle.

A period of 10 years has been taken as the basis of this study. The degree and duration of weather phenomena which are most likely to occur during any year can be determined with a considerable degree of probability from such a period. In any particular year a given condition may have a higher or lower value between the extremes given, but over a period of years the average values given here will be very nearly reproduced. Therefore, computations and decisions should be based upon the average values presented.

## Weather Phenomena Which Contribute to Closed Conditions at the San Francisco International Airport

### Advection Fog

Advection fog is produced by the passage of relatively warm moist air over a colder surface, usually a relatively cold body of water. Since transfer of the air mass is essential, these fogs are always accompanied by winds. Such fogs may be of great depth. At San Francisco, advection fogs are formed over the California current, a cold current flowing south parallel with the coast. Since the fog must move inland, with the westerly sea breeze, over the hills to reach the airport, it seldom lies along the ground at the airport. Adiabatic heating occurs during the downslope movement of the fog in attaining the airport level and dissipates the fog in the lower levels, forming a low ceiling with good horizontal visibility. The surface layer is also warmed by contact with the ground.

### Radiation Fog

Radiation fogs are produced by cooling of the surface layer. Radiation from the earth to the sky on clear nights cools the ground. Surface air is cooled by contact with the ground below its dew point temperature, and fog forms. At San Francisco, radiation fogs form in the air draining from the hills to the west and flowing over the airport. They are very shallow and produce low visibility in the surface layers. They are formed only in calm conditions.

## Frontal Weather Conditions

Frontal weather, characterized by wind, rain, and stratiform clouds, produces low ceilings and reduced visibilities; usually weather conditions remain above operating minimums. Frontal fog is formed by evaporation from warm rain falling through the colder air below, causing it to become saturated and forming fog. This type of fog is seldom found at San Francisco. Whenever frontal fog occurs, it is usually accompanied by moderate wind.

## Water Content of Fogs

The liquid water content of various types of fogs is not, of course, a fixed value at all times and at all places. In the fogs occurring at San Francisco Airport, the water content will seldom exceed the following values:

| | |
|---|---|
| Radiation Fog | 0.2 grams per cubic meter |
| Advection Fog | 0.4 " " " " |
| Pre-frontal Fog | 0.3 " " " " |

The liquid water content of pre-frontal fog is difficult to determine because often this type of fog occurs simultaneously with a perceptible drizzle which invalidates the results obtained with the available means of measurement.

In general, the visibility in a fog is related to both the water content and to the size of the fog particles. The following rough relationship between visibility and liquid water content of fogs may be of interest:

| Visibility in Feet | Liquid Water in $GMS/M^3$ |
|---|---|
| 30 - 150 | (Exceptionally rare) 0.3 - 0.5 |
| 150 - 300 | 0.2 - 0.3 |
| 300 - 600 | 0.2 |
| 600 - 1500 | 0.1 - 0.2 |

## Fog Depths

Radiation fog will rarely exceed 200 feet in depth. This fog forms during near calm conditions; therefore, little vertical mixing occurs and the inversion, an atmospheric condition in which the temperature increases rather than decreases with altitude, is necessarily shallow.

Advection and pre-frontal fogs, which are formed by dynamic processes, are characterized by vertical mixing and are relatively deep (500 - 2000 feet). If these dynamic processes continue, these fogs will persist.

## Terrain Influences

The modifying influence of local terrain contours on weather in a particular locality is well known to meteorologists and pilots. Rarely, however, is the effect of local terrain so clearly seen as at the San Francisco Airport. It is this factor which is mainly responsible for the remarkably low average number of closed hours annually for an airport located within an area of high fog incidence.

A brief review of the main outlines of the terrain is necessary in order to explain their effects upon low visibility conditions. The airport is located on the west bay shore approximately 6 feet above mean sea level. East and south of the airport there are no obstructions of any kind, only the bay and its low-lying shores. West of the field the terrain rises gradually, then steeply, to a maximum elevation of 1300 feet. Northwest of the field the maximum elevation is about 500 feet in the center of a broad "saddle". North-northwest is a peak reaching an elevation slightly over 1300 feet.

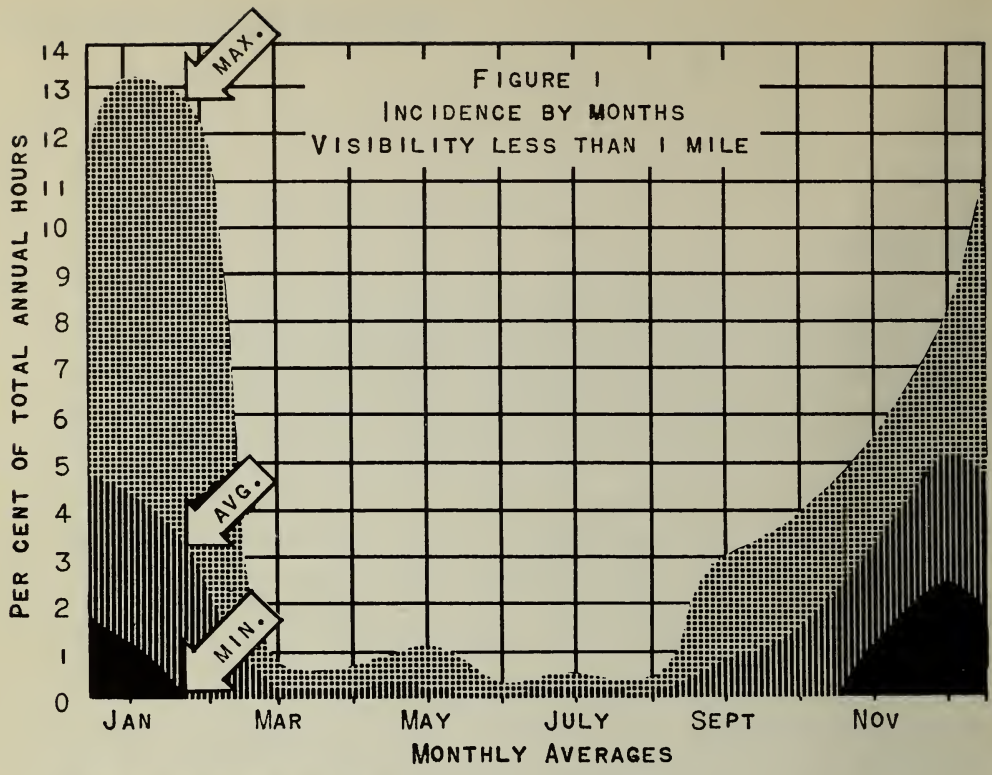


FIGURE 1
INCIDENCE BY MONTHS
VISIBILITY LESS THAN 1 MILE
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

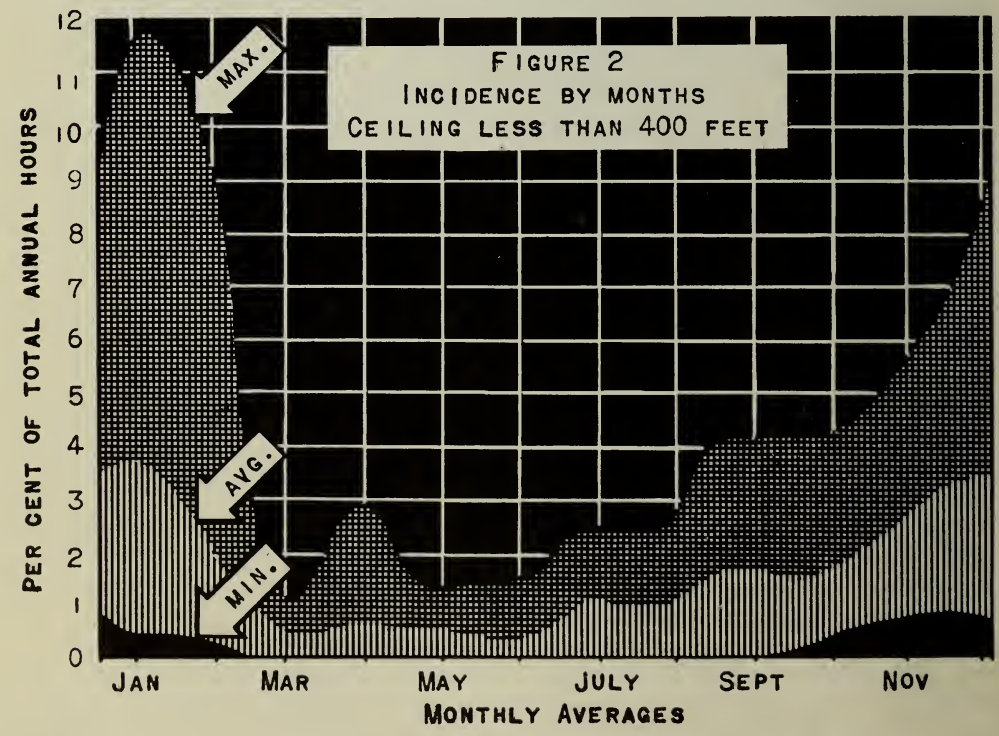


FIGURE 2
INCIDENCE BY MONTHS
CEILING LESS THAN 400 FEET
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

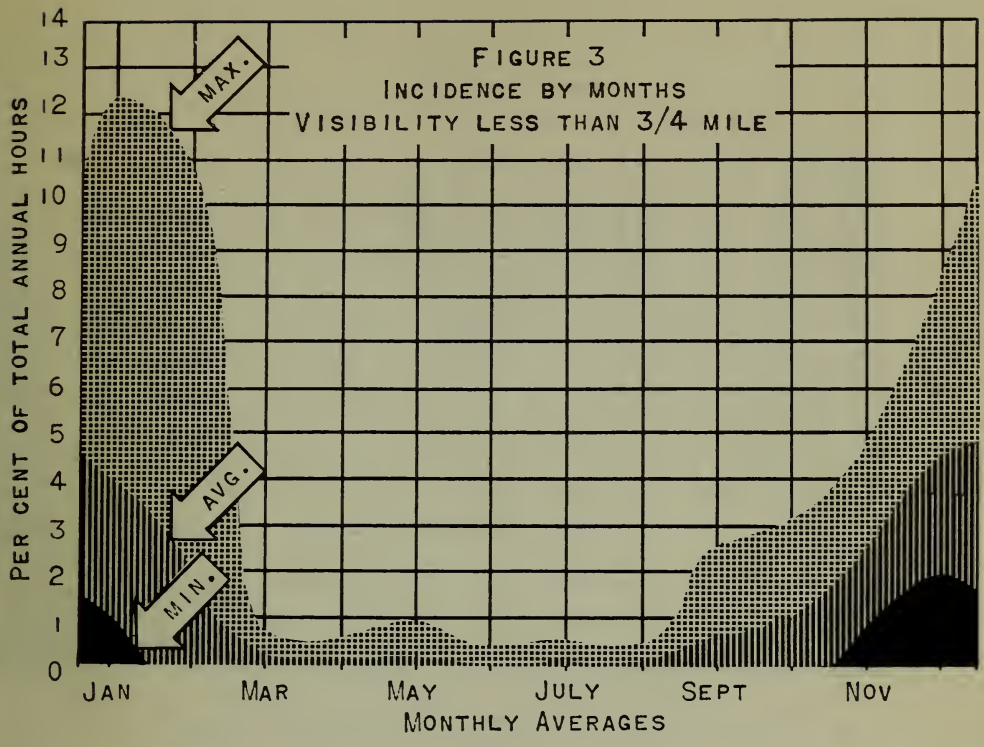


FIGURE 3
INCIDENCE BY MONTHS
VISIBILITY LESS THAN 3/4 MILE
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
JAN MAR MAY JULY SEPT NOV
MONTHLY AVERAGES

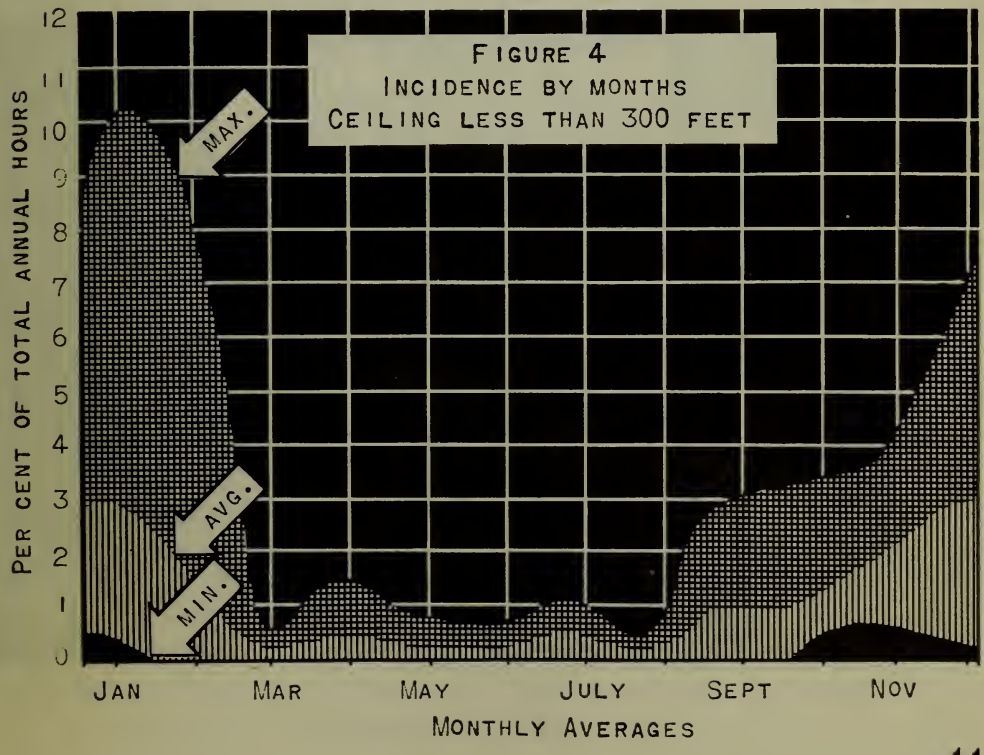


FIGURE 4
INCIDENCE BY MONTHS
CEILING LESS THAN 300 FEET
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0 1 2 3 4 5 6 7 8 9 10 11 12
JAN MAR MAY JULY SEPT NOV
MONTHLY AVERAGES

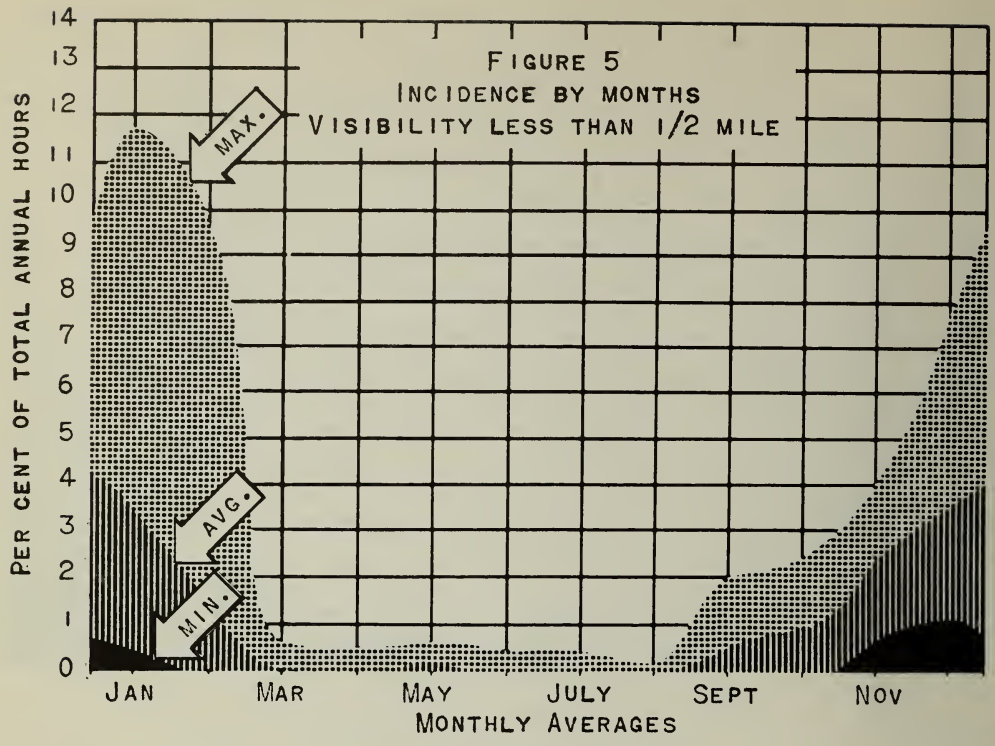


FIGURE 5
INCIDENCE BY MONTHS
VISIBILITY LESS THAN 1/2 MILE
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

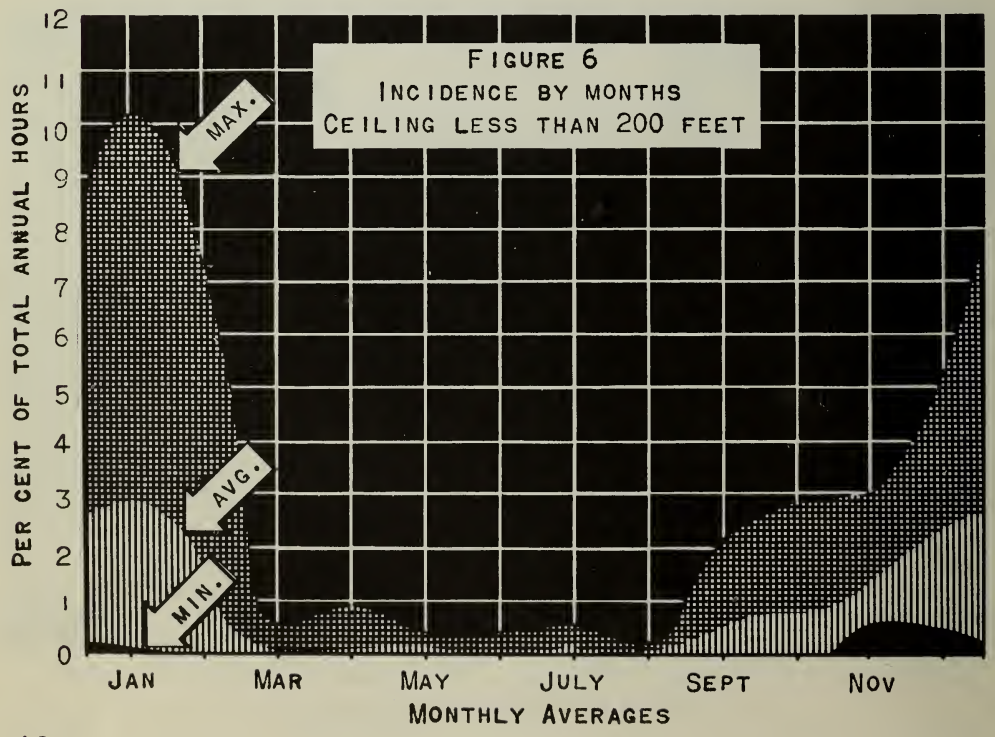


FIGURE 6
INCIDENCE BY MONTHS
CEILING LESS THAN 200 FEET
MAX.
AVG.
MIN.
PER CENT OF TOTAL ANNUAL HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

Prevailing westerly winds are funnelled over the airport through the northwestern "saddle" at a compass direction of about 280 degrees, or roughly parallel with the instrument runway. In the summer months the daily on-shore wind, or sea breeze, produced by diurnal heating inland, funnels through the pass. It reaches maximum velocity at 1400 - 1600 hours. This breeze is the carrier for summer fogs in the California coastal region. However, the San Francisco Airport is sheltered from these fogs. Surface heating from below, combined with adiabatic (down-slope) heating of about 2°F., keep summer fogs above ground at the San Francisco Airport. Low ceiling conditions are common, but do not generally drop below operating minimums, and visibility remains good. Terrain influences, therefore, are largely responsible for the lack of summer fogginess at this airport, as shown in Figs. 1 - 6. Such fog as does occur is seldom the so-called California stratus or advection fog. Usually it is radiation or 'Tule' fog.

As a rule, radiation fog forms at the time of minimum heating in the early morning. It develops over San Francisco Airport on clear, calm nights when the air from the westerly hills cools by radiation and contact with the ground, and, being relatively heavy, flows downward over the airport. It collects in a stagnant shallow-pool colder than air at higher levels, creating an inversion. When the temperature in this local air mass drops below the dew point, shallow radiation fog appears underneath the inversion. Occasionally, 'Tule' fog forms across the bay and drifts over to the airport. The peak of such activity is between 0700 and 0900, as shown in Figs. 7-10.

The expansion of industrial activity in the vicinity of the airport may be producing a gradual trend toward additional low visibility conditions. Smoke and other combustion products are not only in themselves objectionable, but may produce additional fog (or "smog") conditions. Airborne combustion products are often highly hygroscopic, and may cause the formation of fog particles

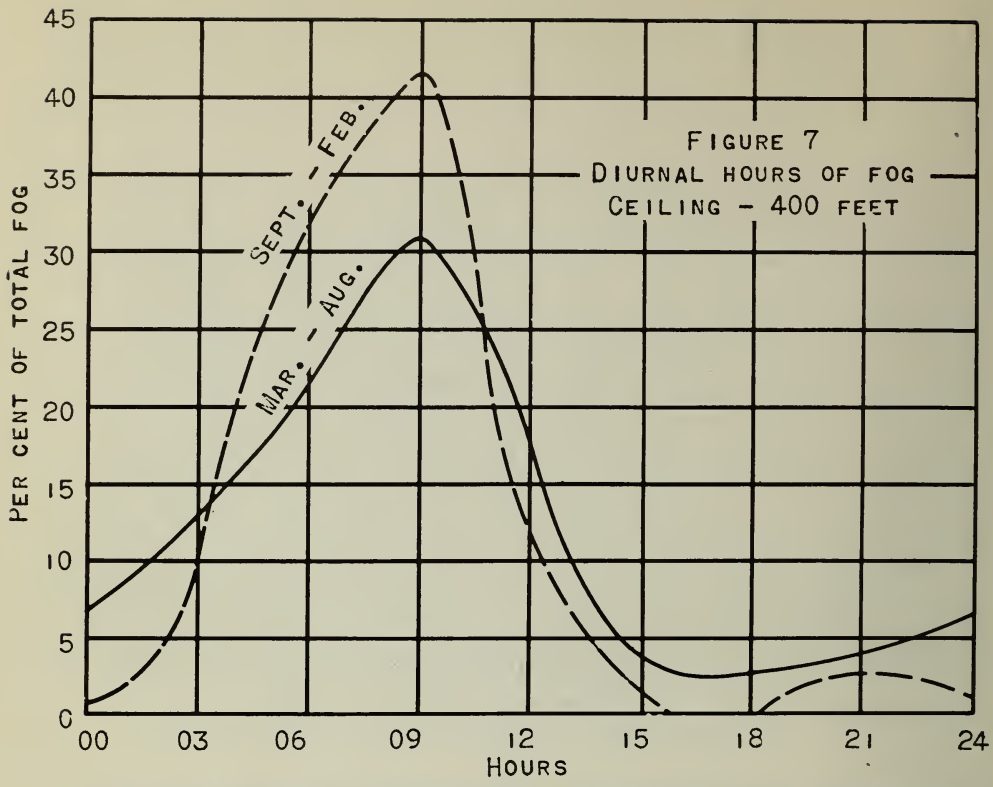



FIGURE 7
DIURNAL HOURS OF FOG
CEILING - 400 FEET

IN MARGINAL HUMIDITY CONDITIONS THAT MIGHT NOT OTHERWISE PRODUCE IT. MOREOVER, THESE PARTICLES WILL BE TRAPPED UNDER THE FREQUENTLY OCCURRING INVERSIONS OF THIS LOCALITY. EVEN WITHOUT ACCOMPANYING FOG THEY MAY SERIOUSLY REDUCE VISIBILITY.

## OPERATING CONDITIONS

AT PRESENT, INSTRUMENT FLIGHT INTO AND OUT OF SAN FRANCISCO CAN CONTINUE WHEN THE CEILING IS NOT LESS THAN 400 FEET AND THE VISIBILITY IS 1 MILE OR MORE. HOWEVER, AFTER HIGH INTENSITY APPROACH AND RUNWAY LIGHTS HAVE BEEN INSTALLED, PLANES EQUIPPED WITH THE CAA INSTRUMENT LANDING SYSTEM, AND OPERATED BY PILOTS TRAINED IN ILS, WILL BE ALLOWED TO LAND WITH 300-FOOT CEILING AND VISIBILITY 3/4 MILE. AFTER 6 MONTHS OF SUCCESSFUL OPERATION, THE MINIMUMS WILL BE REDUCED TO 200 FEET AND 1/2 MILE. IT IS, THEREFORE, NECESSARY TO PRESENT SEPARATE ANALYSES FOR EACH CONDITION.

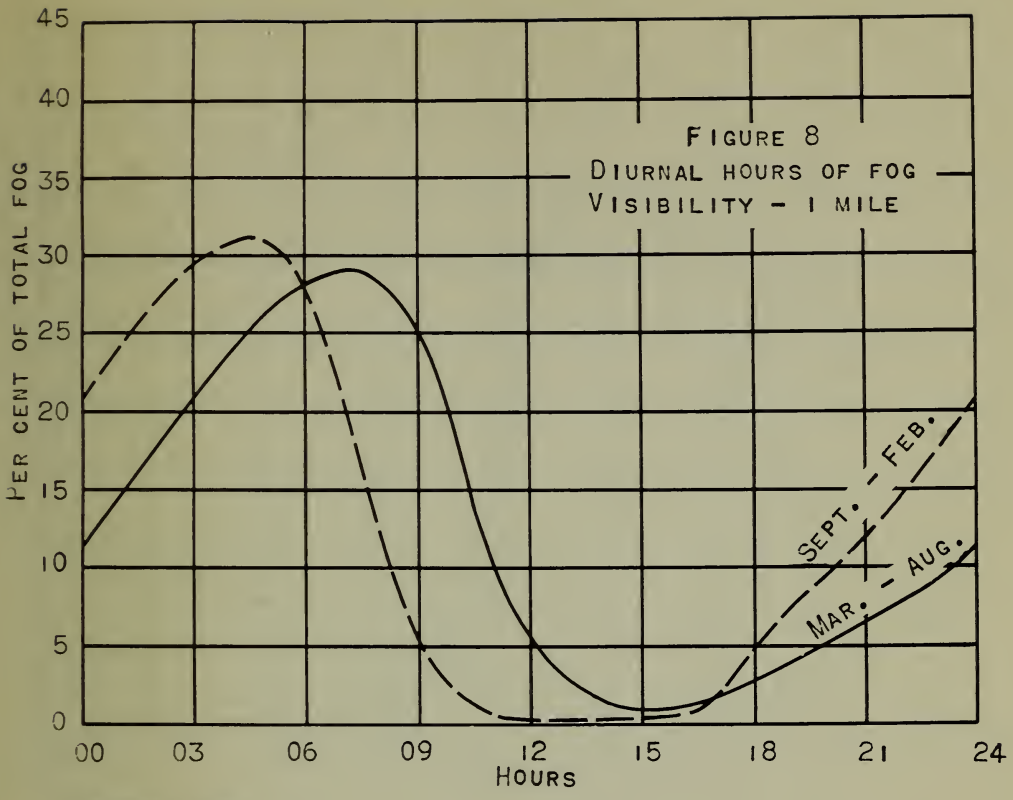
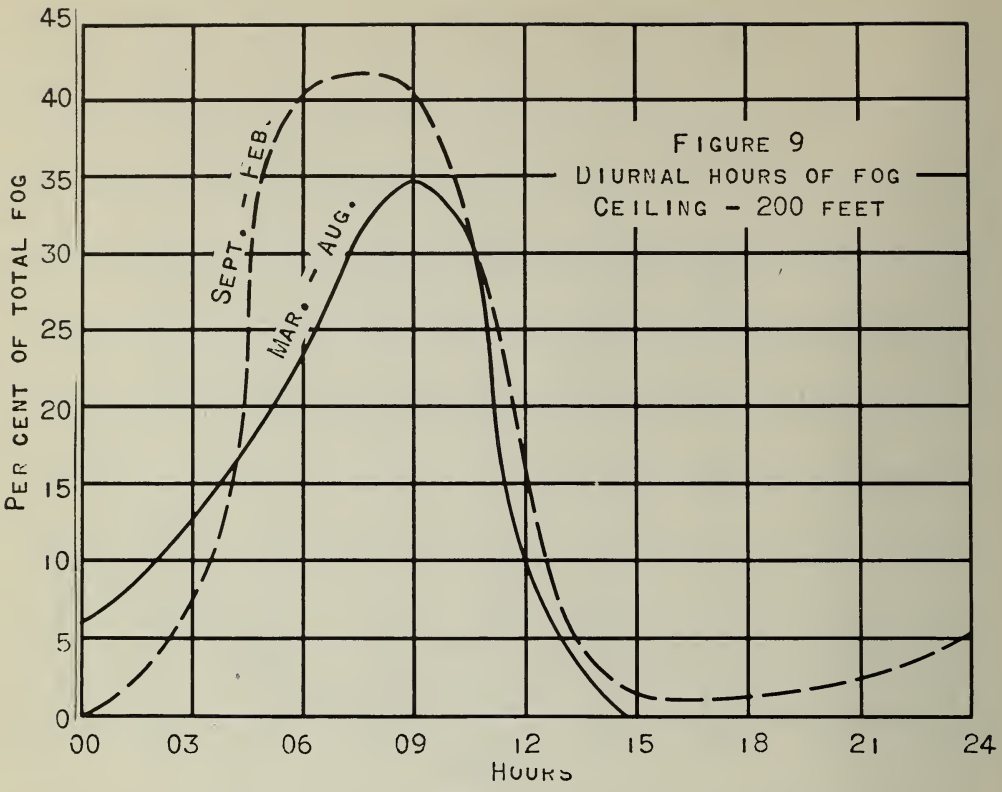



FIGURE 8
DIURNAL HOURS OF FOG
VISIBILITY - 1 MILE

## TABULATIONS

TABULATIONS OF THE SAN FRANCISCO WEATHER DATA ARE PRESENTED GRAPHICALLY. A MAXIMUM, AN AVERAGE, AND A MINIMUM VALUE ARE GIVEN, WHENEVER POSSIBLE, FOR EACH WEATHER CONDITION. WHEN PLANNING FOR ACTIVITIES WHICH WILL BE INFLUENCED BY WEATHER CONDITIONS, THE AVERAGE VALUES SHOULD BE USED SINCE THESE VALUES ARE THE MOST CONSERVATIVE. HOWEVER, IT MUST BE KEPT IN MIND THAT IT IS POSSIBLE, EVEN THOUGH HIGHLY IMPROBABLE, FOR ALL THE MONTHLY MAXIMUM VALUES TO OCCUR DURING ONE YEAR OR FOR ALL THE MONTHLY MINIMUM VALUES TO OCCUR DURING ANOTHER YEAR.

THE BASIC OBSERVATION UNIT USED IN TABULATION WAS ONE HOUR, SINCE MOST OF THE OBSERVATIONS WERE TAKEN AT THIS INTERVAL. WHERE MORE FREQUENT OBSERVATIONS WERE AVAILABLE, THE HOURLY TOTALS HAVE BEEN ADJUSTED TO REFLECT THE ACTUAL DURATIONS. USE OF HOURLY INTERVALS




INTRODUCES A SMALL ERROR INTO MINIMUM INCIDENCE TOTALS, SINCE FOG AT THE TIME OF OBSERVATION IS ASSUMED TO HAVE LASTED A FULL HOUR. ALSO, THE MINIMUM DURATION OF FOG IS NECESSARILY 1 HOUR, ALTHOUGH SHORTER FOGS MAY ACTUALLY OCCUR.

## DURATION OF CLOSED CONDITIONS BY MONTHS, FIGS. 11 - 16

A STUDY OF WEATHER CONDITIONS OVER THE PAST TEN YEARS SHOWS THAT CEILINGS WILL BE BELOW 400 FEET AND/OR VISIBILITY BELOW 1 MILE 1.9% OF THE TIME, ON THE AVERAGE, OR A TOTAL OF 167 HOURS PER YEAR. THE CLOSED TIME CAN BE AS MUCH AS 8.3% OF THE TIME, AT THE MAXIMUM, OR 720 HOURS IN A YEAR.

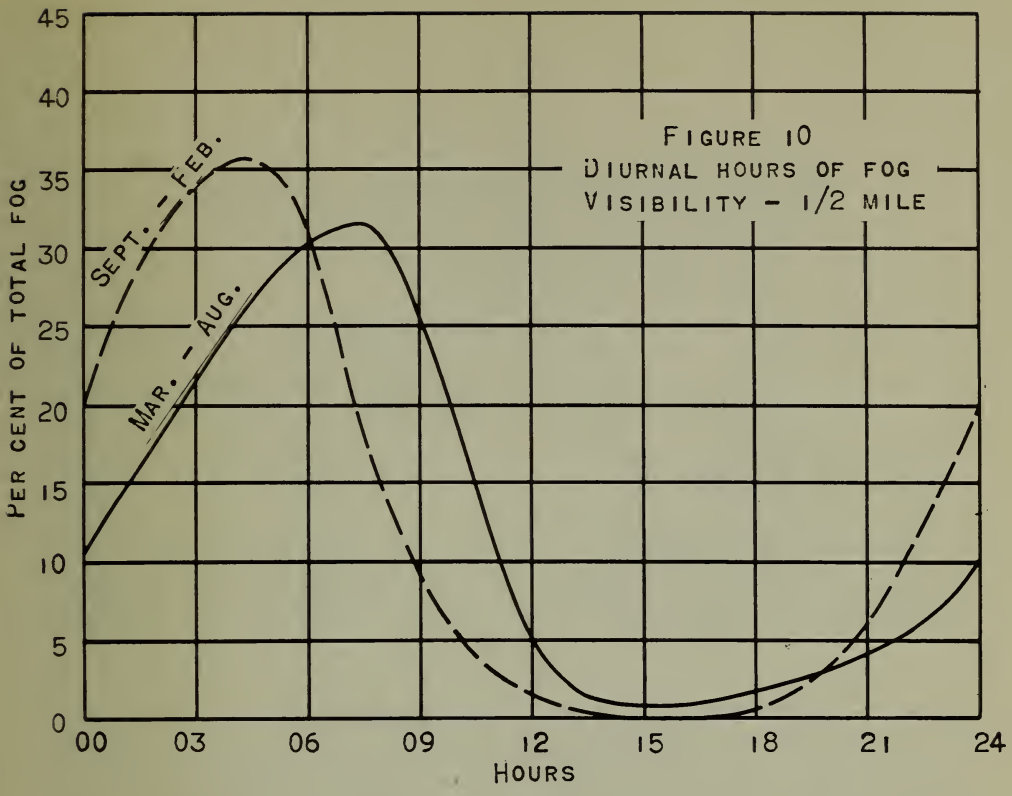



FIGURE 10
DIURNAL HOURS OF FOG
VISIBILITY - 1/2 MILE

CEILING AND VISIBILITY WILL BE BELOW 300 FEET AND/OR 3/4 MILE, ON THE AVERAGE, 1.4% OF THE TIME, OR 123 HOURS. THE MAXIMUM EXPECTED IN ANY ONE YEAR IS 6.2% OR 545 HOURS.

CEILING AND VISIBILITY WILL BE BELOW 200 FEET AND/OR 1/2 MILE, ON THE AVERAGE, 1.1% OF THE TIME, OR 96 HOURS PER YEAR. THE MAXIMUM EXPECTED IS 4.7% OR 412 HOURS IN ANY ONE YEAR.

LOW VISIBILITY AT SAN FRANCISCO FOLLOWS A WELL DEFINED ANNUAL CYCLE OF OCCURRENCE, WITH MAXIMUM INCIDENCE IN THE WINTER MONTHS, REGARDLESS OF THE VARIATION FROM YEAR TO YEAR IN THE TOTAL NUMBER OF HOURS. THE FOLLOWING ARE THE MOST ESSENTIAL RELATIONSHIPS TO BE DRAWN FROM THE FIGURES:

Percentage of Total Annual Closed Hours
Occurring During Fall and Winter Months

| | September 1 to February 28 | November 1 to February 28 |
|---|---|---|
| Visibility below 1 mile | 96% | 85% |
| Ceiling below 400 feet | 80% | 62% |
| Visibility below 3/4 mile | 95% | 85% |
| Ceiling below 300 feet | 89% | 73% |
| Visibility below 1/2 mile | 96% | 85% |
| Ceiling below 200 feet | 95% | 83% |

These figures show that ceilings below 200 feet are almost identical in occurrence with general low visibility conditions. The two higher ceilings considered often occur at San Francisco without a correlative restriction in visibility at the surface. However, the overwhelming majority of low ceiling and visibility conditions, by total average duration, occur during the fall and winter months. More than three-quarters of the closed conditions will occur, on the average, between November 1 and February 28.

Time of Occurrence of Low Visibility Conditions, Figs. 7-10

In addition to the annual cycle, low ceilings and visibilities follow a diurnal pattern set up by the change in insolation to the earth's surface. The following values are of particular significance:

Percentage of Total Annual Closed Hours
Occurring during Certain Diurnal Periods

| | 0000-0900 | 0000-1200 | 2100-1200 |
|---|---|---|---|
| Visibility below 1 mile | 72% | 87% | 93% |
| Ceiling below 400 feet | 72% | 81% | 91% |
| Visibility below 1/2 mile | 74% | 89% | 95% |
| Ceiling below 200 feet | 74% | 88% | 94% |

The values for visibility less than 3/4 mile and ceiling less than 300 feet need not be considered here because the three sets of values are nearly identical.

Figs. 7-10 show that nearly all of the low ceilings and visibilities occur between midnight and noon. Most of the closed conditions at the San Francisco Airport result from radiation fog. Therefore, it is expected that the low visibilities should occur during the hours of minimum heating. Fog over the airport restricts the solar insolation and the ground does not warm up sufficiently to dissipate it until 0900. The fogs which do occur between noon and 1800 are persistant fogs which remain for 24 hours.

These figures are of importance because it is expected that as traffic expands, more transcontinental, transpacific, and feeder arrivals will be scheduled during the morning hours.

The daily period of maximum incidence during the months of maximum incidence (September through February) is 0600 - 0900. This is also the period in which maximum schedule expansion is likely to occur.

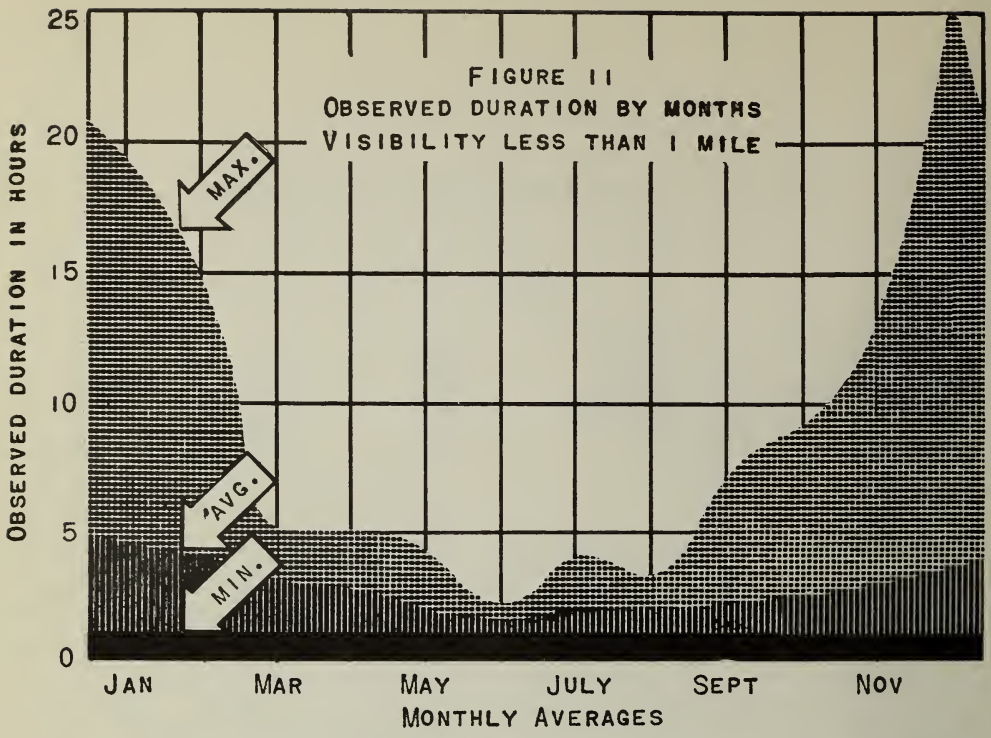


FIGURE 11
OBSERVED DURATION BY MONTHS
VISIBILITY LESS THAN 1 MILE
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

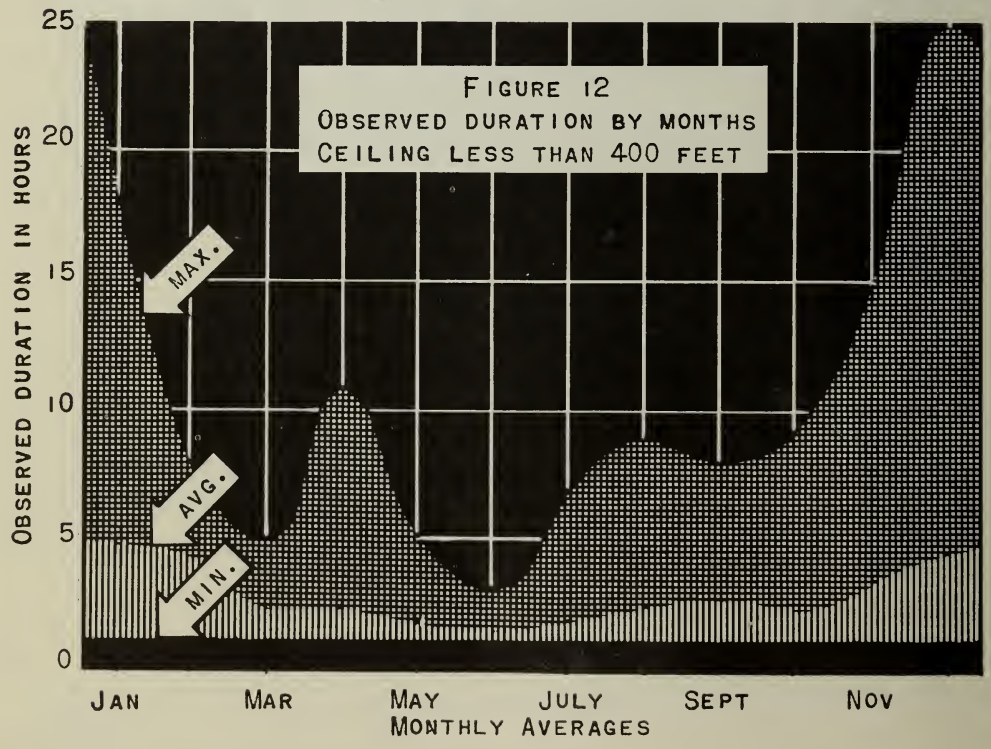


FIGURE 12
OBSERVED DURATION BY MONTHS
CEILING LESS THAN 400 FEET
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

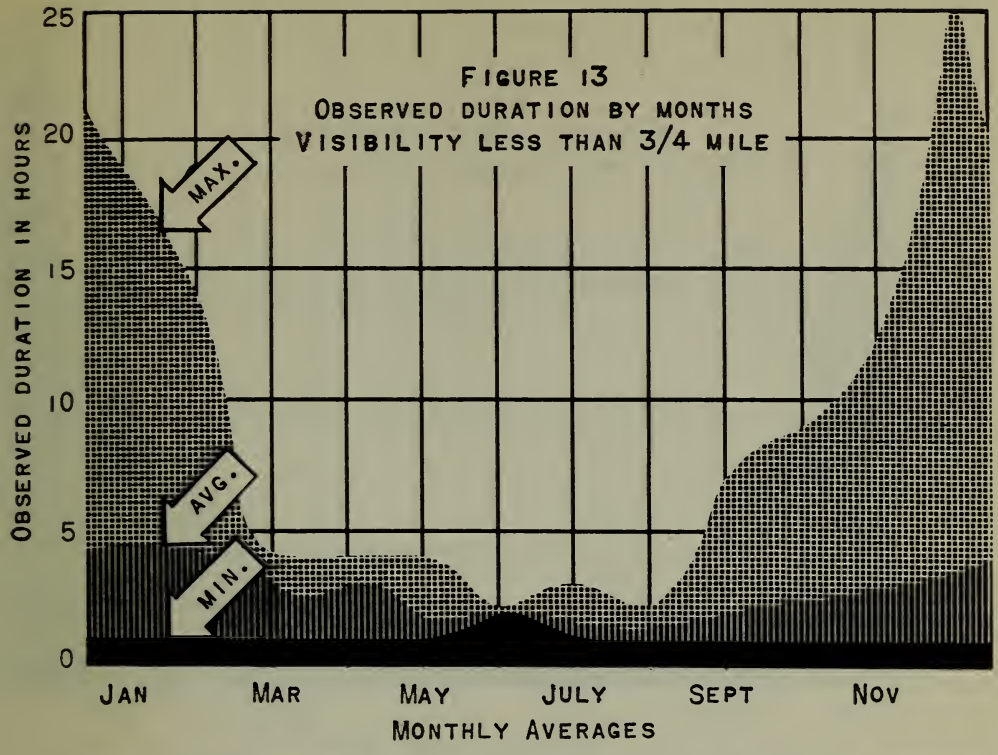


FIGURE 13
OBSERVED DURATION BY MONTHS
VISIBILITY LESS THAN 3/4 MILE
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

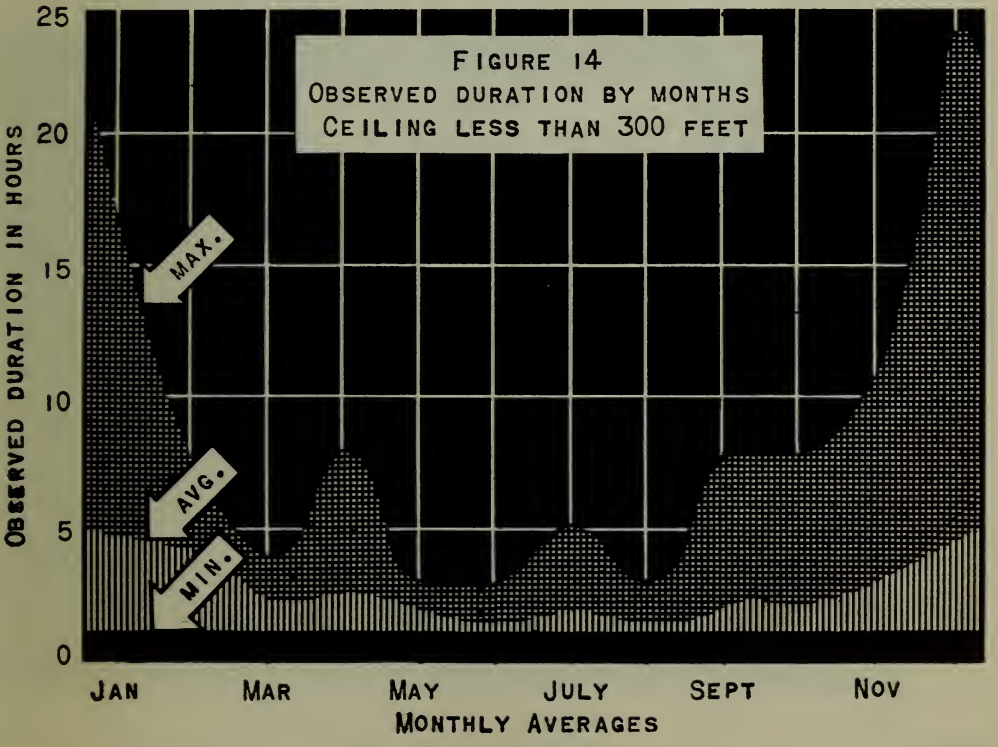


FIGURE 14
OBSERVED DURATION BY MONTHS
CEILING LESS THAN 300 FEET
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

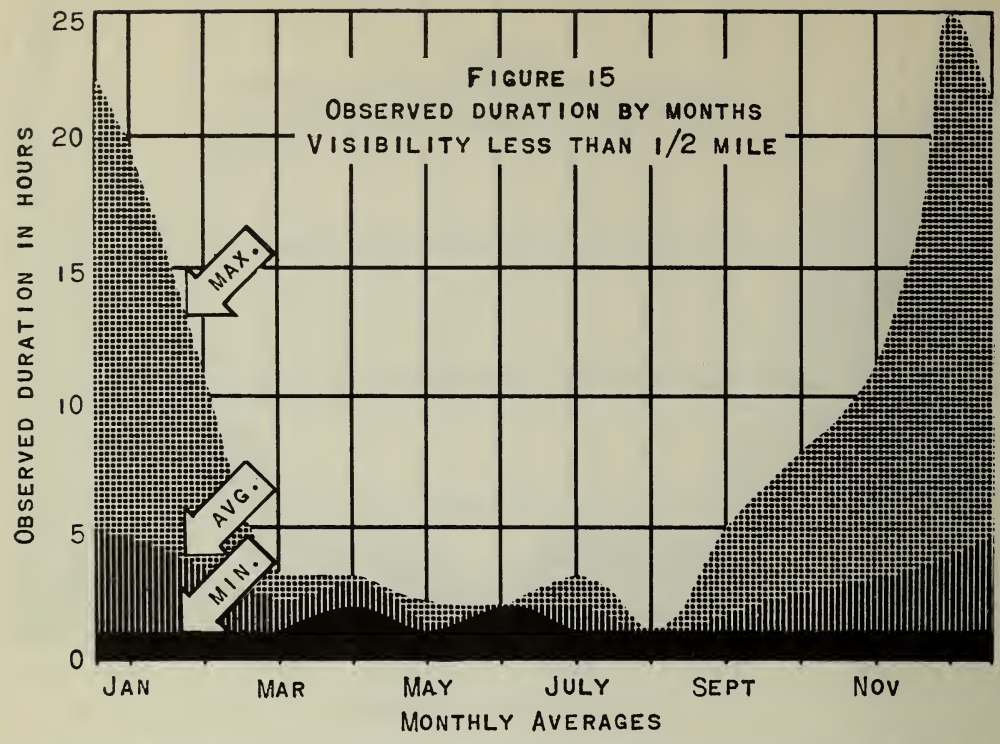


FIGURE 15
OBSERVED DURATION BY MONTHS
VISIBILITY LESS THAN 1/2 MILE
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

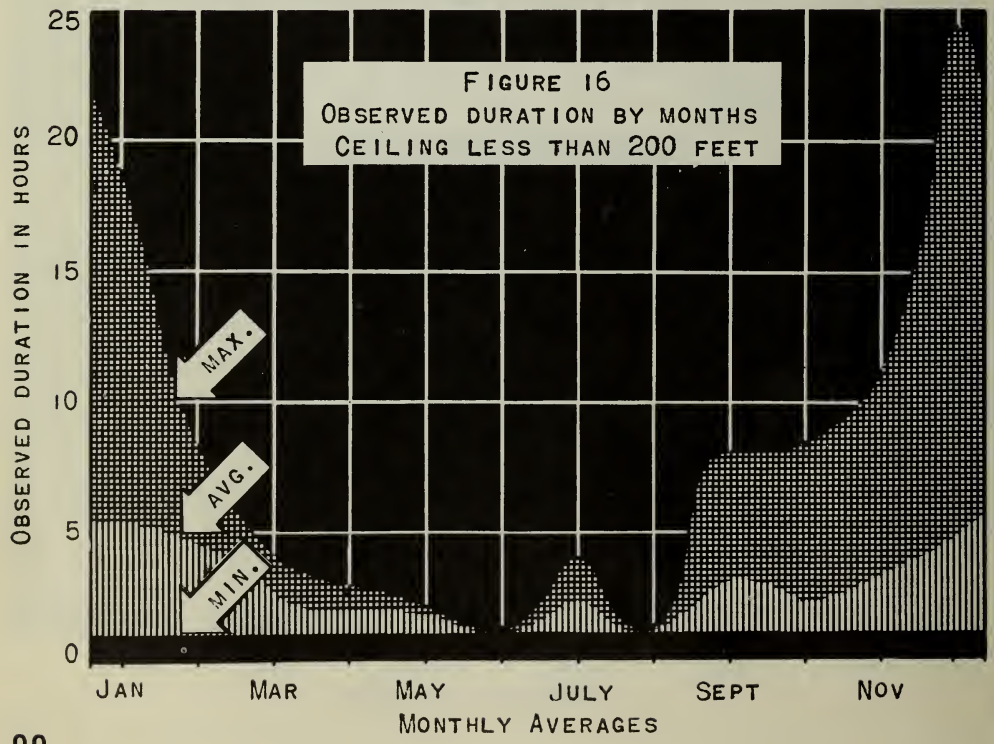


FIGURE 16
OBSERVED DURATION BY MONTHS
CEILING LESS THAN 200 FEET
OBSERVED DURATION IN HOURS
25
20
15
10
5
0
MAX.
AVG.
MIN.
JAN
MAR
MAY
JULY
SEPT
NOV
MONTHLY AVERAGES

## Duration of Low Visibility Conditions, Figs. 11 - 16

The probable duration of fog is nearly as important in aircraft scheduling as its occurrence. The following values will serve as a guide:

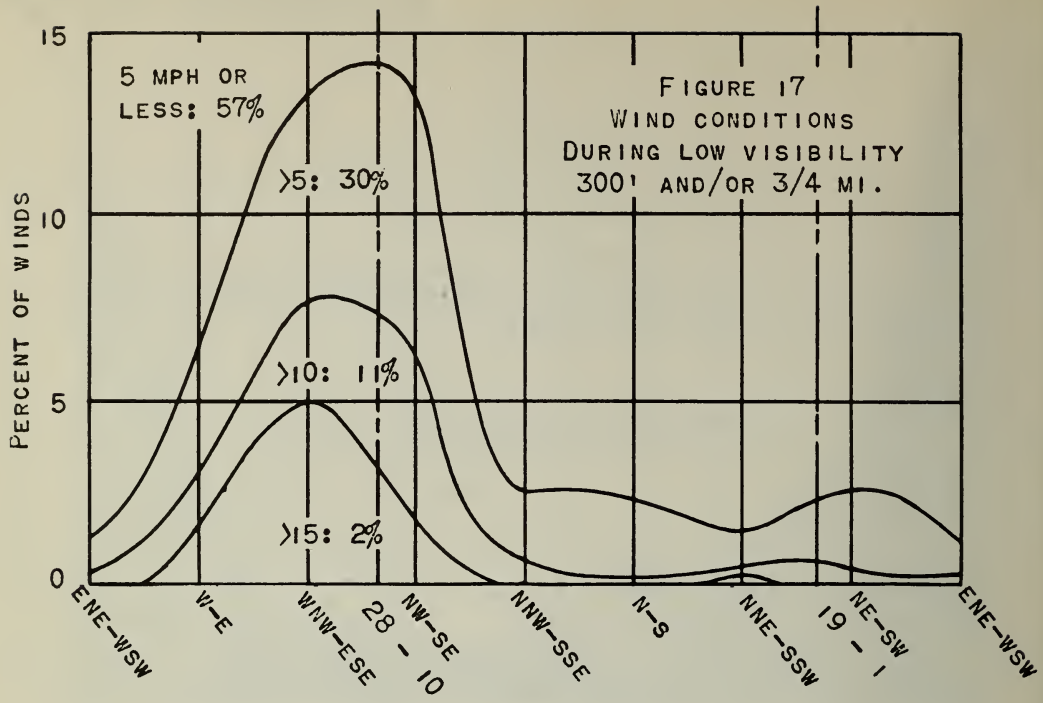
Observed Fog Duration in Hours

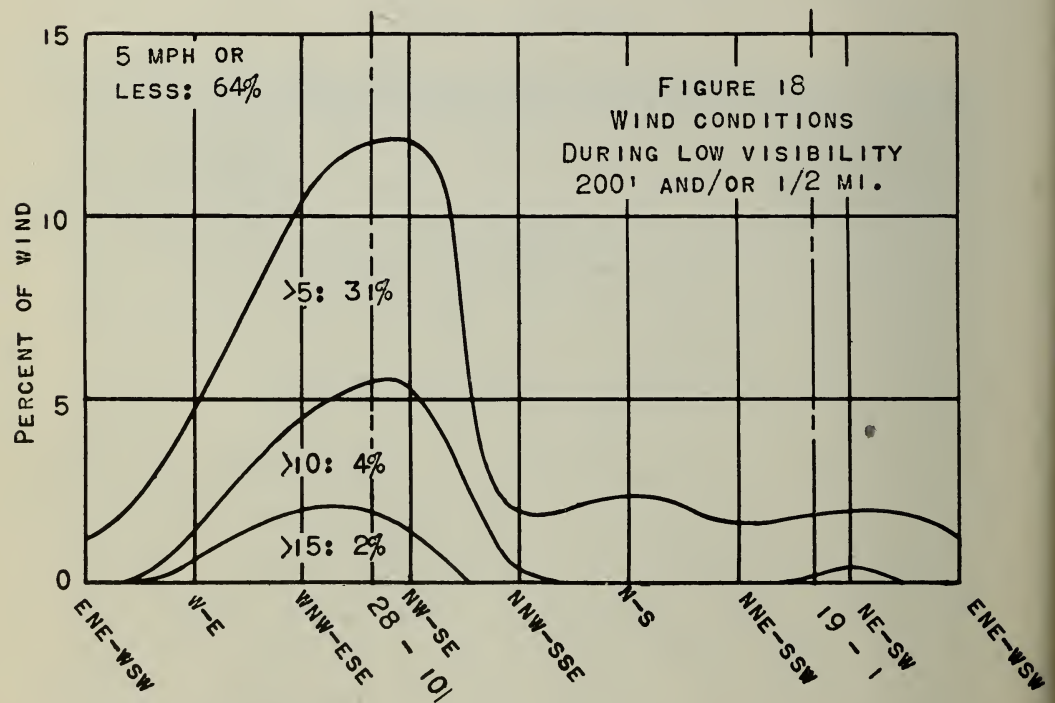
| | Maximum | Average | Minimum |
|---|---|---|---|
| Visibility below 1 mile | 24 | 3.9 | 1 |
| Ceiling below 400 feet | 26 | 4.3 | 1 |
| Visibility below 3/4 mile | 24 | 3.8 | 1 |
| Ceiling below 300 feet | 24 | 4.1 | 1 |
| Visibility below 1/2 mile | 24 | 3.7 | 1 |
| Ceiling below 200 feet | 24 | 4.2 | 1 |

Most fogs can be expected to last in the neighborhood of 4 hours before natural clearing processes bring an end to closed conditions. It is obvious that schedules into and out of San Francisco Airport are seriously upset by fogs of this duration. Planes cannot be safely stacked up over a four-hour period and each year a great many must be shifted to alternate airports. Likewise, many departing schedules are held for hours on the ground.

## Wind Conditions Accompanying Low Visibility

Calm wind conditions are the rule with very low visibility conditions at the San Francisco Airport. Winds will accompany advection and frontal fogs, but will never occur with radiation fog. Figs. 17 - 18 show that in low visibility conditions winds generally blow along the instrument runway, rarely crossing it at an angle in excess of 30 degrees. Wind conditions are not a major problem at the San Francisco Airport during low visibility, and Runway 28R can be used for most adverse weather landings.


15
10
5
0
PERCENT OF WINDS
5 MPH OR LESS: 57%
>5: 30%
>10: 11%
>15: 2%
FIGURE 17
WIND CONDITIONS
DURING LOW VISIBILITY
300' AND/OR 3/4 MI.
ENE-WSW
W-E
WNW-ESE
28 - 10
NW-SE
NNW-SSE
N-S
NNE-SSW
19 - 1
NE-SW
ENE-WSW


15
10
5
0
PERCENT OF WIND
5 MPH OR LESS: 64%
>5: 31%
>10: 4%
>15: 2%
FIGURE 18
WIND CONDITIONS
DURING LOW VISIBILITY
200' AND/OR 1/2 MI.
ENE-WSW
W-E
WNW-ESE
28 - 10
NW-SE
NNW-SSE
N-S
NNE-SSW
19 - 1
NE-SW
ENE-WSW

More than half of the low visibility conditions, on the average, will be accompanied by winds less than 5 miles per hour. Only rarely will winds greater than 10 miles per hour accompany low visibility conditions. A breakdown of records over the ten-year period by visibility and ceiling conditions shows the following relationships:

Visibility 3/4 mi. and/or less - Ceiling 300' and/or less
Average: 126 hours Maximum: 545 hours

| Wind Velocity | Per Cent of Closed Time | Average Hours Per Year | Maximum Hours Per Year |
|---|---|---|---|
| Less than 5 mph | 57% | 70 | 310 |
| 5 - 9 mph | 30% | 37 | 164 |
| 10 - 14 mph | 11% | 14 | 60 |
| Greater than 15 mph | 2% | 2 | 11 |

Visibility 1/2 mi. and/or less - Ceiling 200' and/or less
Average: 96 hours Maximum: 412 hours

| Wind Velocity | Per Cent of Closed Time | Average Hours Per Year | Maximum Hours Per Year |
|---|---|---|---|
| Less than 5 mph | 65% | 61 | 265 |
| 5 - 9 mph | 31% | 30 | 129 |
| 10 - 14 mph | 4% | 4 | 17 |
| Greater than 15 mph | 2% | 2 | 8 |

FIGURE 19

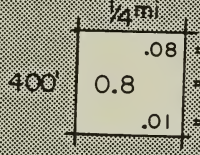
NATURE AND ANNUAL DURATION OF CLOSED CONDITIONS

TOTALS OF ANNUAL HOURS, AVERAGE PERCENT, AND MAXIMUM PERCENT OF CLOSED TIME CAN BE DETERMINED FOR EACH OF THE VARIOUS MINIMUM OPERATING CONDITIONS BY THE ADDITION OF ALL THE FIGURES SHOWN IN THE CLOSED BLOCK FOR THAT CONDITION. OPEN HOURS ARE DETERMINED BY SUBTRACTION, AS SHOWN IN THE FOLLOWING TABLE.

ANNUAL OPEN TIME AT
SAN FRANCISCO INTERNATIONAL AIRPORT
(1 YEAR = 8760 HOURS)

| MINIMUM OPERATING CONDITION | | AVERAGE | | MINIMUM | |
|---|---|---|---|---|---|
| CEILING | VISIBILITY | HOURS | PERCENT | HOURS | PERCENT |
| 400' | 1 mile | 8592 | 98.1 | 8010 | 91.7 |
| 300' | $\frac{3}{4}$ mile | 8636 | 98.6 | 8190 | 93.7 |
| 200' | $\frac{1}{2}$ mile | 8658 | 99.0 | 8320 | 95.2 |

KEY




= MAXIMUM TOTAL : 0.08 % OF TOTAL YEARLY TIME

= AVERAGE TOTAL : 0.8 HOURS PER YEAR

= AVERAGE TOTAL : 0.01 % OF TOTAL YEARLY TIME

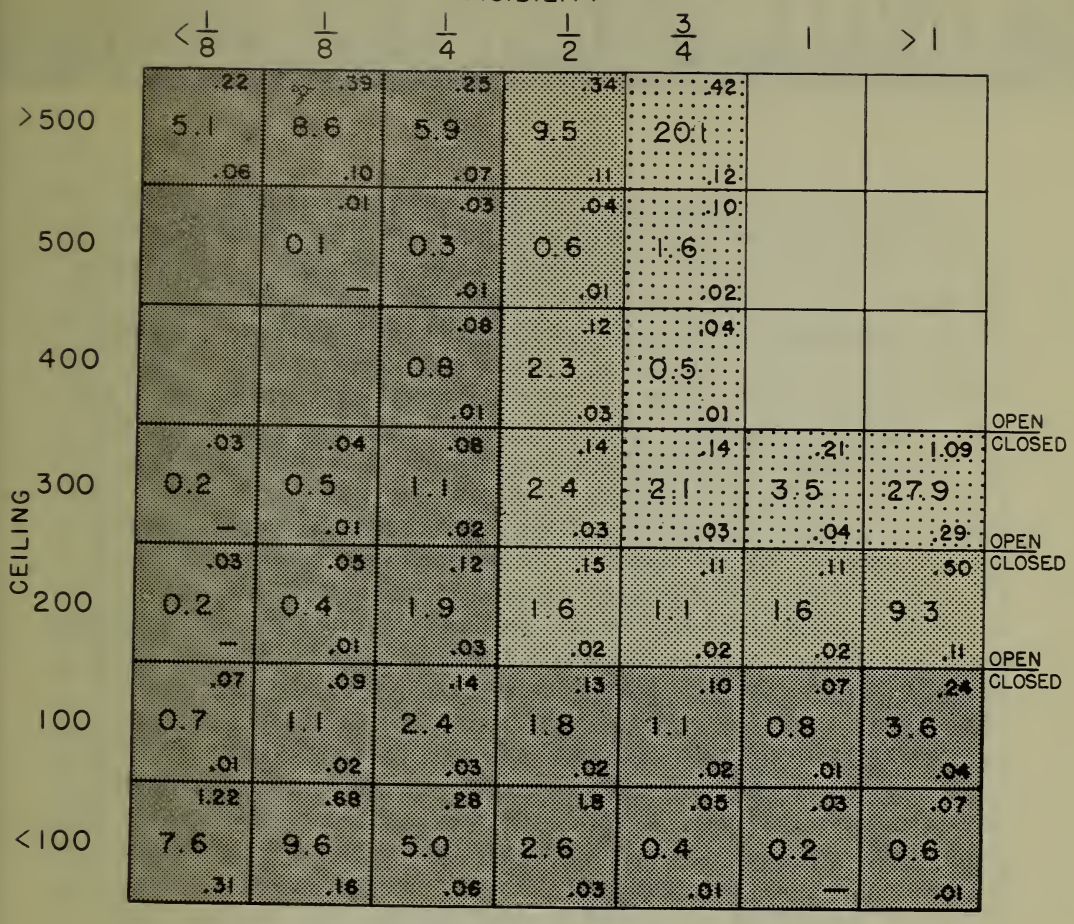
SUMMARY

(1) ADVECTION FOG (OR "SEA FOG"), WHICH IS FAMILIAR TO RESIDENTS OF THE CITY OF SAN FRANCISCO, IS LESS TROUBLESOME AT THE SAN FRANCISCO AIRPORT THAN MIGHT BE EXPECTED. THE INFLUENCE OF THE TERRAIN NEAR THE AIRPORT IS SUCH THAT, IN MANY CASES, ADVECTION FOG MOVING IN FROM THE SEA ARRIVES OVER THE AIRPORT AS LOW-HANGING STRATUS.

(2) A LARGER PROPORTION OF THE FOG WHICH CLOSES THE AIRPORT IS RADIATION FOG, CAUSED BY THE RADIATIONAL LOSS OF HEAT FROM THE EARTH ON CLEAR, CALM NIGHTS.

(3) ON THE AVERAGE, THE CEILING AND/OR VISIBILITY WILL BE AT OR BELOW:

FIGURE 19




400 FEET AND 1 MILE, 167 HOURS PER YEAR
300 FEET AND 3/4 MILE, 123 HOURS PER YEAR
200 FEET AND 1/2 MILE, 96 HOURS PER YEAR

(4) THE AVERAGE DURATION OF LOW VISIBILITY AND/OR LOW CEILING IS 4 HOURS, BUT MAY OCCASIONALLY LAST 24 HOURS.

(5) SEVENTY-FIVE PER CENT OF THE LOW VISIBILITY AND/OR LOW CEILING OCCURS BETWEEN MIDNIGHT AND 9 A.M.

(6) NINETY PER CENT OF THE LOW VISIBILITY AND/OR LOW CEILING OCCURS BETWEEN 1 SEPTEMBER AND 28 FEBRUARY.

(7) NINETY-FIVE PER CENT OF THE WINDS ACCOMPANYING LOW VISIBILITY AND/OR LOW CEILING ARE BELOW 10 MPH, AND 65 PER CENT ARE BELOW 5 MPH.

# TRAFFIC ANALYSIS

The goal of San Francisco International Airport is to make possible the achievement of 100 per cent schedule reliability. This is to be done, as nearly as is practicable, by installing landing aids which will make it completely safe for aircraft to land or take off without delay in all expected weather conditions. The word "practicable" implies that landing aids must be evaluated in economic terms as well as from the standpoint of operational effectiveness. To do so requires a consideration of traffic through the airport, both in terms of scheduled arrivals and departures, and in terms of the remunerative units--the passengers and cargo carried. The landing aids installations required to assure the landing and departure of every plane on schedule must not price air transportation out of its potential market. This study cannot undertake to establish the potential market for absolutely reliable aerial transportation beyond the general statement that absolute reliability would greatly increase the present usage of such transportation, which, in turn, will materially decrease the unit cost. It can derive principles by which the economic value of landing aids can be determined in relation to present schedules, and suggest the effect of established trends on this value.

## Past History

Figs. 20, 21, and 22 record the development of air traffic through San Francisco Airport since 1934 in terms of the yearly totals of aircraft operations (arrivals plus departures), passengers carried (in and out), and cargo carried (outbound only; inbound figures are not available). The curves follow the general trend of all industrial activities during the Thirties, with a slump occurring after 1936. The sharper decrease in plane operations in 1937 - 1939, as compared with the lesser

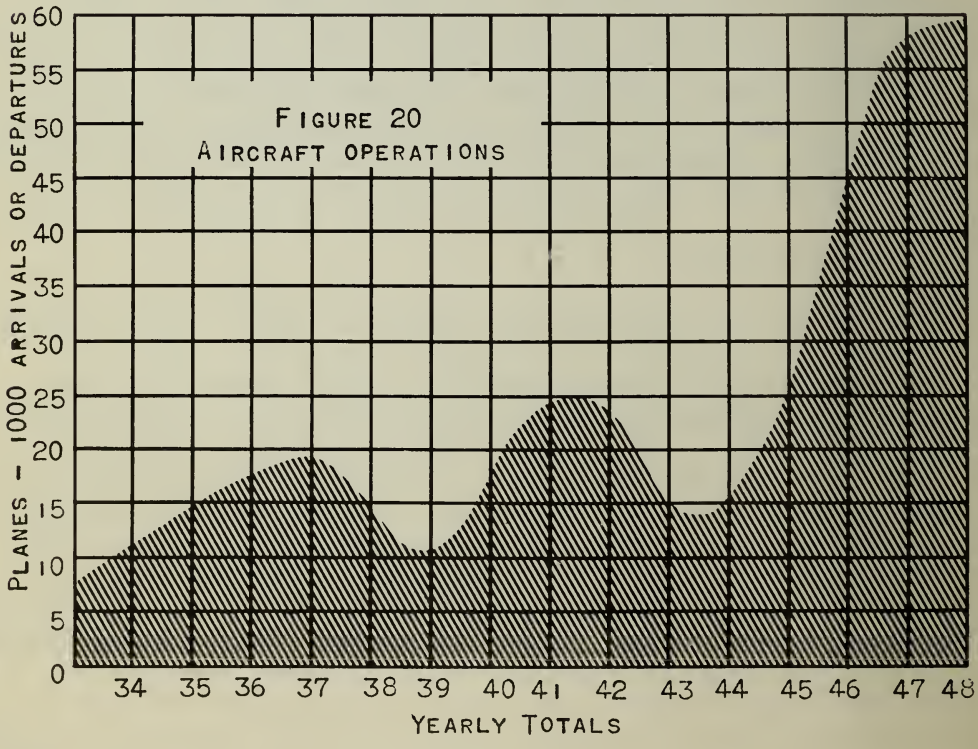
SLUMP IN PASSENGERS AND CARGO, MAY REFLECT THE INTRODUCTION OF PLANES WITH A LARGER PAYLOAD FACTOR DURING THIS PERIOD, PARTICULARLY THE WIDESPREAD ADOPTION OF THE DC-3 IN AIRLINE SERVICE. THE 1939 LOW IN OPERATIONS AND CARGO REFLECTS THE MARCH TO MAY PERIOD OF THAT YEAR WHEN AIRPORT CONSTRUCTION AND REPAIRS RESTRICTED OPERATION; PASSENGER TRAFFIC APPEARS NOT TO HAVE BEEN GREATLY AFFECTED THEREBY. THE 1939 - 1942 PREWAR PERIOD SHOWS A MARKED INCREASE IN ALL CATEGORIES. DURING THE WAR PERIOD SCHEDULED OPERATIONS DROPPED SHARPLY, WHILE PASSENGER TRAFFIC AND CARGO LOADINGS LEVELLED OFF, INDICATING THAT EXISTING EQUIPMENT WAS BEING MORE FULLY LOADED, AND POSSIBLY THAT STILL LARGER PLANES WERE BEING PLACED IN SERVICE. BEGINNING IN 1944, ALL THREE CURVES RISE SHARPLY. PASSENGER TRAVEL HAS INCREASED ESPECIALLY FAST SINCE 1945, REFLECTING THE END OF RESTRICTIONS ON AIRLINE EXPANSION AND THE GENERAL PROSPERITY. CARGO LOADINGS LAGGED UNTIL 1946, POSSIBLY BECAUSE OF GREATER EMPHASIS ON PASSENGER TRAFFIC, PERHAPS ALSO AS A RESULT OF THE RECONVERSION PERIOD. IN 1947, OPERATIONS LEVELLED OFF, AND PASSENGER TRAFFIC ALSO APPEARS TO BE ENTERING ANOTHER PLATEAU. CARGO LOADING IS STILL RISING, ACCORDING TO THE LATEST AVAILABLE FIGURES.

## FUTURE EXPANSION

IT MAY BE EXPECTED THAT TRAFFIC THROUGH SAN FRANCISCO AIRPORT WILL EXPAND CONTINUOUSLY THROUGH THE YEARS, IF WORLD CONDITIOUS REMAIN SUBSTANTIALLY UNCHANGED AND NO CRITICAL GENERAL ECONOMIC COLLAPSE DEVELOPS. AMONG THE IMPORTANT LOCAL CONDITIONS FAVORING SUCH AN INCREASE IS THE FACT THAT SAN FRANCISCO IS A MARKED CENTER OF GRAVITY IN STATE INDUSTRY AND POPULATION TRENDS. THE INCREASING POPULATION AND INCREASING INDUSTRIAL ACTIVITY WITHIN THE STATE (THE MOST MARKED INCREASE NOW IN PROCESS IN THE UNITED STATES) IS CONCENTRATED IN SUCH CENTERS. THIS WILL INEVITABLY RESULT IN RISING AIR TRAFFIC, BOTH IN PASSENGERS

AND CARGO, BETWEEN SAN FRANCISCO AND OTHER LOCAL AND NATIONAL CENTERS. FEEDER LINES--ALREADY WELL ESTABLISHED AS A CALIFORNIA AERIAL FREIGHT AND PASSENGER BUSINESS--AND ALSO TRUNK LINES, WILL NEED TO OPERATE MORE SCHEDULES FROM THE SAN FRANCISCO AIRPORT. FEEDER LINES SHOULD EXPERIENCE A SIZABLE EXPANSION BECAUSE OF THE GREAT DISTANCES BETWEEN MAJOR ECONOMIC AND CULTURAL CENTERS, WITH A RESULTANT FUNNELLING OF LARGE VOLUMES OF TRAFFIC INTO THE SAN FRANCISCO AIRPORT.

A SECOND MAJOR CAUSE OF INCREASED TRAFFIC AT THIS POINT IS ITS COASTAL LOCATION AND ITS PROXIMITY TO THE HAWAIIAN ISLANDS. SAN FRANCISCO WILL INEVITABLY BE THE MOST SUITABLE TERMINUS FOR MUCH INTERNATIONAL AIR TRAVEL, PROVIDED ITS FACILITIES ARE ADEQUATE. RECONSTRUCTION AND EXPANSION OF INDUSTRIAL AND COMMERCIAL ACTIVITY ACROSS THE PACIFIC WILL BRING ABOUT A SUSTAINED INCREASE IN TRANS-PACIFIC PASSENGER AND CARGO LOADING. THE ENCOURAGEMENT



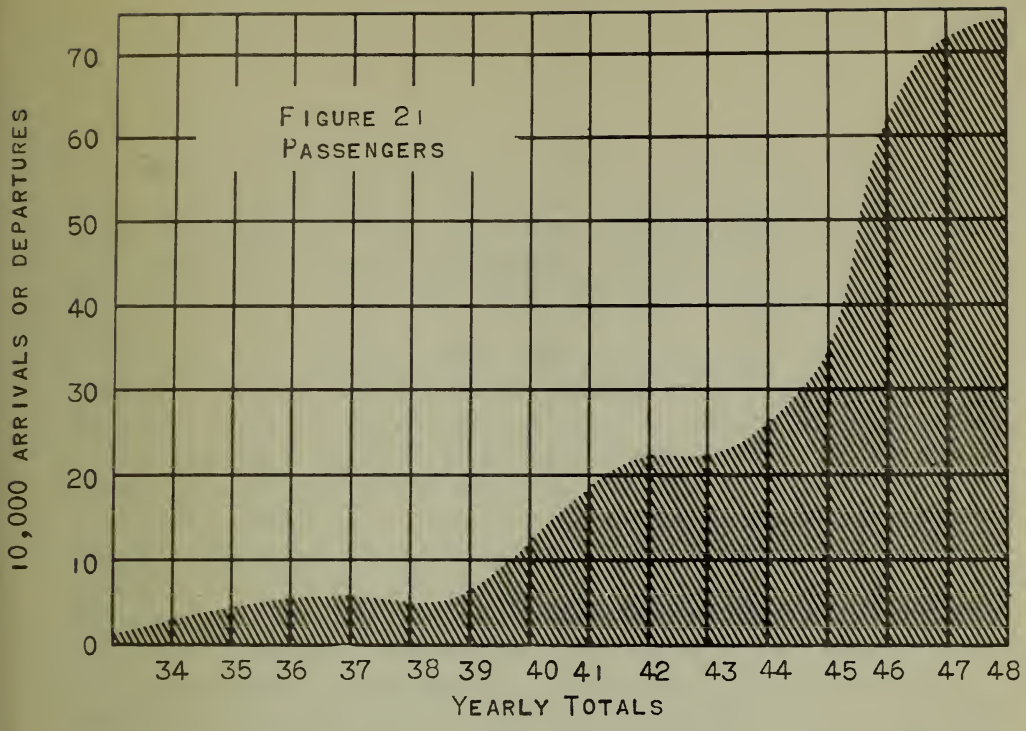


FIGURE 21
PASSENGERS
10,000 ARRIVALS OR DEPARTURES
0
10
20
30
40
50
60
70
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
YEARLY TOTALS

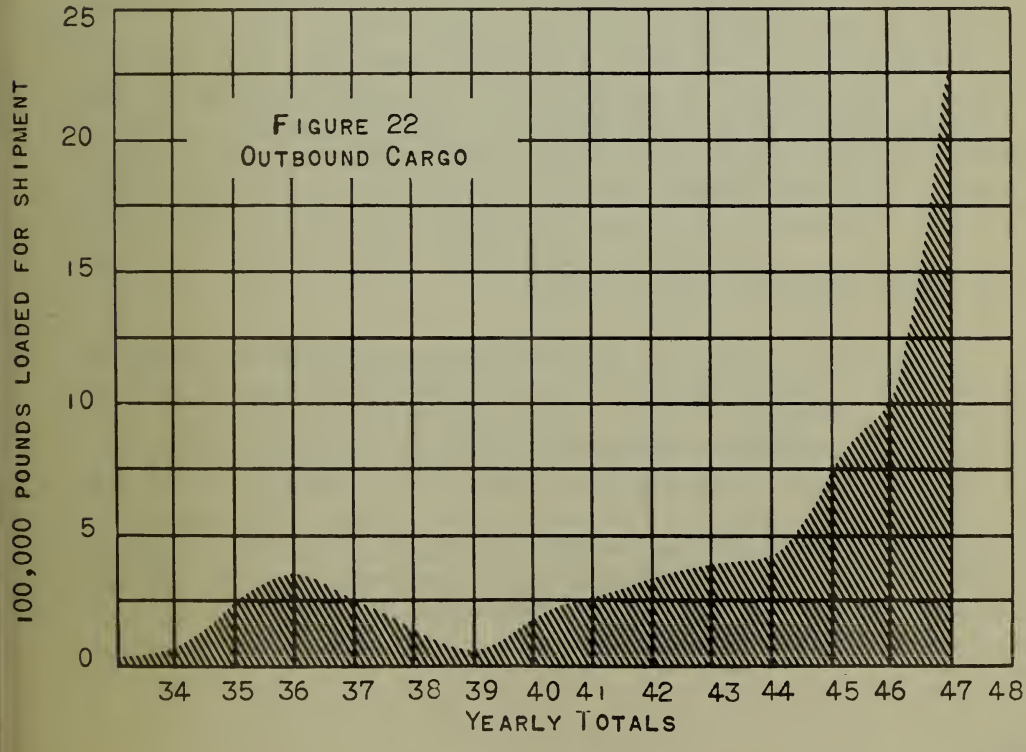


FIGURE 22
OUTBOUND CARGO
100,000 POUNDS LOADED FOR SHIPMENT
0
5
10
15
20
25
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48
YEARLY TOTALS

OF AND PARTICIPATION IN SUCH EXPANSION IS BOTH AN IMPORTANT IDEAL AND A PRACTICAL ECONOMIC NECESSITY TO THE FUTURE WELL-BEING OF THIS COUNTRY. WE CAN, THEREFORE, ASSUME THAT AN INCREASE IN TRADE VOLUMES WITH NATIONS IN THE PACIFIC WILL BE A NATIONAL POLICY.

THE PAST 14 YEARS HAVE SEEN THE FLEDGLING AVIATION INDUSTRY BECOME AN IMPORTANT FACTOR IN THE NATION'S TRANSPORTATION. ALTHOUGH IT MAY BE QUESTIONED WHETHER ANOTHER 14 YEARS WILL BRING ABOUT A SIMILAR 25-FOLD INCREASE IN PASSENGER TRAVEL AND CARGO LOADING AT SAN FRANCISCO, A CONTINUED EXPANSION SEEMS INEVITABLE. THE SIZE, STEADINESS AND SOUNDNESS OF SUCH GROWTH WILL BE MATERIALLY FORWARDED IF SAN FRANCISCO AIRPORT IS ABLE TO PROVIDE FACILITIES INSURING RELIABLE SCHEDULES. SINCE ALMOST ALL OF THE TRAFFIC WHICH MUST GO BY AIR IS ALREADY AIRBORNE, THE FUTURE INCREASE WILL BE DRAWN FROM THAT PORTION OF THE POTENTIAL WHICH WOULD GO BY AIR IF DEPARTURES AND ARRIVALS WERE ABSOLUTELY RELIABLE, AND OUT OF THE GREATER POTENTIAL RESULTING FROM HIGHER LEVELS OF COMMERCIAL ACTIVITY. ESTIMATES OF THE POSSIBLE EXPANSION VARY, BUT ALL SOURCES AGREE THAT IT WILL BE LARGE, AND WILL DEPEND PRIMARILY ON INCREASED SAFETY AND RELIABILITY, WITH DECREASING COST BECOMING SIGNIFICANT AS INCREASING PAYLOAD FACTORS PERMIT MORE ECONOMICAL OPERATION.

## THE TREND TOWARD LARGER PLANES

IN 1933 - 1934 THE AVERAGE PASSENGER LOAD PER PLANE OPERATION AT SAN FRANCISCO WAS IN THE NEIGHBORHOOD OF 2.6 PERSONS. IN 1946 - 1947 THE AVERAGE PASSENGER LOAD WAS ABOUT 12.4 PERSONS PER PLANE OPERATION. (NOTE: SINCE SEPARATE FIGURES ARE NOT AVAILABLE FOR PASSENGER AND CARGO FLIGHTS, THIS FIGURE IS SMALLER THAN THE ALL-PASSENGER LOADING.) ALTHOUGH THE NUMBER OF PLANES ARRIVING INCREASED ONLY ABOUT 5 TIMES, THE NUMBER OF PASSENGERS INCREASED BY 25 TIMES, AND THE WEIGHT OF OUTBOUND CARGO BY 23 TIMES. THE TREND TOWARD LARGER AND FASTER PLANES IS CONTINUING,

PARTICULARLY ON TRUNK AIRLINES, AS SHOWN BY THE FOLLOWING TABLE OF PASSENGER CAPACITIES:

Aircraft Passenger Capacity

| Type | Passenger Load Day | Passenger Load Sleeper | Put in Service |
|---|---|---|---|
| DC-3 | 21 | | 1935 |
| DC-4 | 44-58 | | 1943 |
| Constellation | 64 | 34 | 1945 |
| DC-6 | 52 | 26 | 1947 |
| Stratocruiser | 64-114 | 30-55 | Pending |
| Constitution | 100-128 | | Pending |
| Convair | 40 | | Pending |

Use of bigger planes tends to reduce the number of operations scheduled. However, the expansion of feeder lines will operate to arrest or even reverse this trend, percentagewise, since these lines will probably continue to operate smaller plane types, and will aim to provide more frequent service of the commuter type.

Summary of Established Trends

The factors discussed above show that while passenger and cargo transportation through San Francisco International Airport will steadily expand in volume, the number of scheduled daily arrivals and departures will not increase at the same rate. The present average of 7 scheduled plane movements per hour (see Fig. 23) is, therefore, a satisfactory basis for initiating a landing aids program adequate to handle traffic schedules within the next five years.

# DAILY AIRCRAFT SCHEDULES

## ARRIVALS

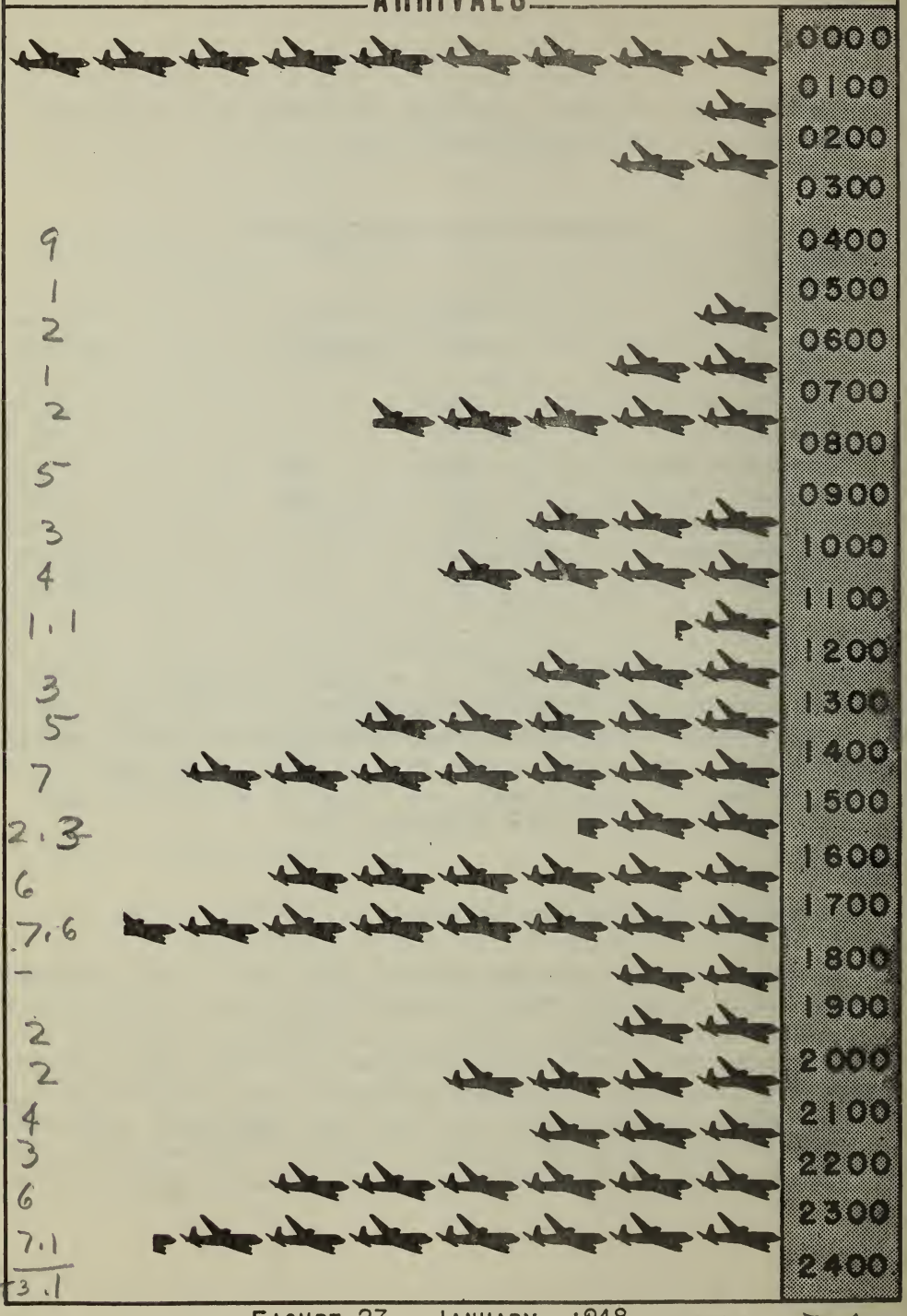



FIGURE 23 - JANUARY, 1948



80.9
83.1
164.0

17-18
16-17

7.6
5
12.6
6

# DAILY AIRCRAFT SCHEDULES

## DEPARTURES

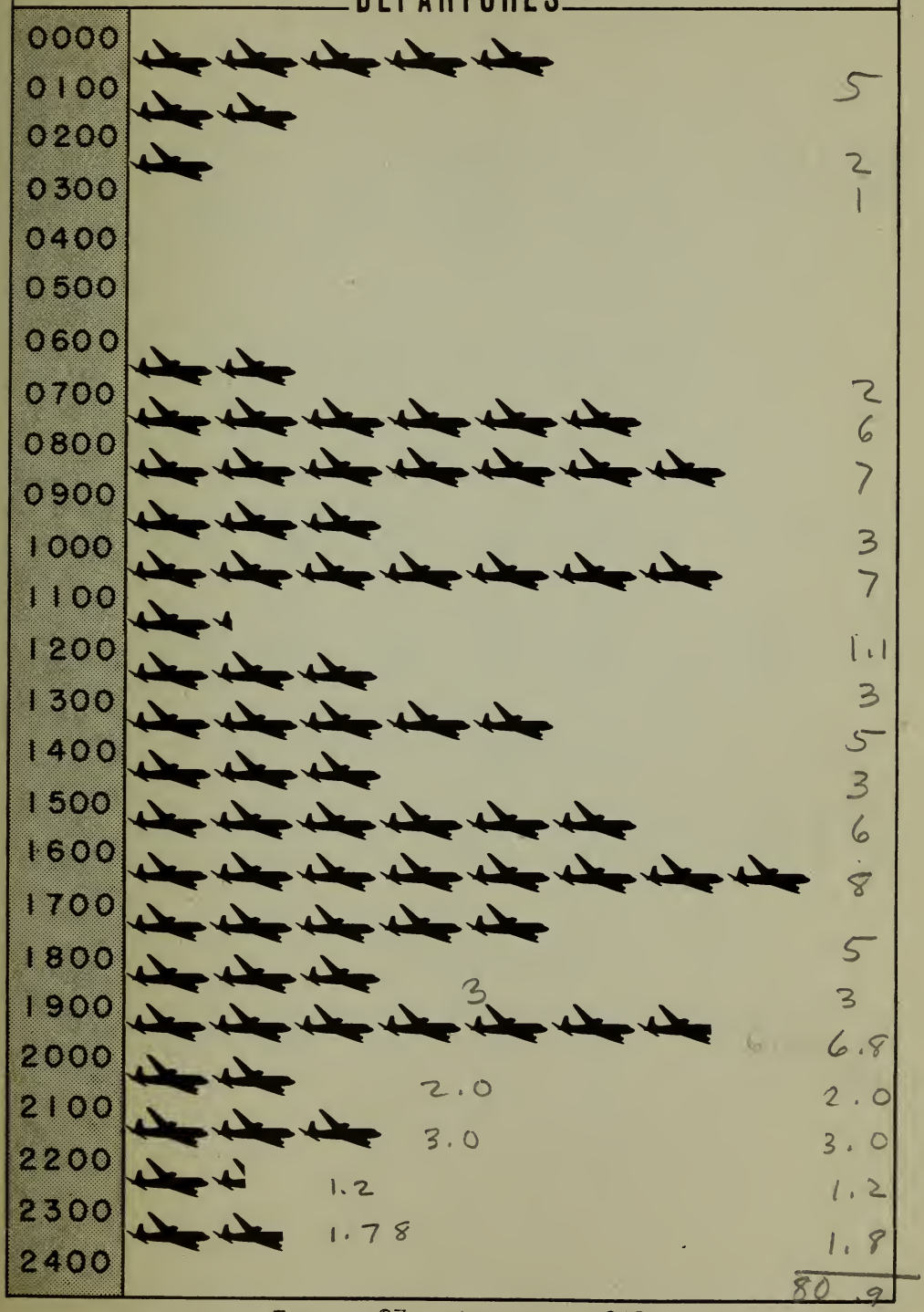



FIGURE 23 - JANUARY, 1948



$\frac{14}{164}$ = 8.5% of daily movements in peak hour 4-5 PM

## January 1948 Schedules Projected Through the Year

| | | Arrivals | Departures |
|---|---|---|---|
| 0000 - 1200 | | 10,000 planes | 12,000 planes |
| 1200 - 2400 | | 20,000 planes | 18,000 planes |
| | Total | 30,000 planes | 30,000 planes |

## Annual Totals of Schedules Interrupted by Low Visibility

### 0000 - 1200

| Minimum Condition | Arrivals | | Departures | | Totals | |
|---|---|---|---|---|---|---|
| | Avg | Max | Avg | Max | Avg | Max |
| 200' & 1/2 mi. | 102 | 457 | 124 | 558 | 226 | 1015 |
| 300' & 3/4 mi. | 133 | 600 | 161 | 750 | 294 | 1350 |
| 400' & one mi. | 182 | 795 | 221 | 967 | 409 | 1762 |

### 1200 - 2400

| | | | | | | |
|---|---|---|---|---|---|---|
| 200' & 1/2 mi. | 12 | 60 | 11 | 55 | 23 | 115 |
| 300' & 3/4 mi. | 20 | 80 | 18 | 73 | 38 | 153 |
| 400' & one mi. | 23 | 100 | 21 | 92 | 44 | 192 |

### Yearly Totals

| | | | | | | |
|---|---|---|---|---|---|---|
| 200' & 1/2 mi. | 114 | 517 | 135 | 613 | 249 | 1130 |
| 300' & 3/4 mi. | 153 | 680 | 179 | 823 | 332 | 1503 |
| 400' & one mi. | 205 | 895 | 242 | 1059 | 447 | 1954 |

## Interrupted Schedules

With ILS and high intensity airport lighting, the CAA contemplates a stepwise reduction of operating minimums, first to 300-foot ceiling and 3/4 mile visibility; then, after 6 months' successful operation, to 200-foot ceiling and 1/2 mile visibility. The effect of these reductions on "closed" time at San Francisco has been presented earlier in terms of per cents and hours per year for years of average and of maximum incidence of low visibility and ceiling. It is important here to know how these reductions affect scheduled operations. In preparing the table of anticipated schedule interruptions, the schedules for January 1948 have been taken as a basis for the calculation. Since most of the fog occurs in the diurnal period 0000-1200, schedules in this period have been considered separately from those in the period 1200-2400.

These figures indicate the general order of interruptions caused by conditions below prospective minimums. They show the degree of need for a FIDO installation which can modify weather conditions to meet the minimums. The calculations upon which they are based assume equal spacing of the flights within the period considered and an equal probability of interruption by below minimum weather regardless of the schedule's location within the 12-hour period. Neither condition is true, since the natural tendency is to group schedules during the hours fog has least often been observed. However, this might not be true if FIDO were available. The figures can be extrapolated to include additional schedules by simple proportion.

It should be pointed out that the meteorological analysis shows an average low visibility duration of 4 hours. That is, aircraft will frequently spend upwards of 4 hours in stacks, or else will be diverted or cancelled at the source.

## Air Traffic Planning

The decisive point for San Francisco Airport operations is the number of plane arrivals per unit of time, since departures are cared for by the duplicate runways. The saturation point is 30 planes per hour, or one plane each 2 minutes. Provided each landing is properly conducted and each aid is in perfect order, planes could be handled at this rate. However, the level of experience among present pilots and operations personnel makes a much less frequent scheduling advisable.

It is unlikely that San Francisco will be faced with handling this volume of scheduled traffic in the near future. As has been pointed out, the increase since 1933 (from 1.2 to 7 plane movements per hour) represented the initial mushroom growth. Further schedule expansion should occur at a moderate rate, particularly in view of the steady trend toward larger planes with heavier passenger and cargo loadings.

Meanwhile, steps should be taken to organize traffic for all-weather operation and train airport and airline personnel for the critical days. Schedules, in peak periods, should be limited to 2-minute intervals as an

ABSOLUTE MINIMUM; THAT IS, THE EXPECTED TRAFFIC LOAD SHOULD NEVER BE ALLOWED TO EXCEED THE CAPACITY OF THE FIELD IN MINIMUM CONDITIONS. GREATER SPACING SHOULD BE KEPT WHEREVER POSSIBLE UNTIL PILOTS AND TOWER PERSONNEL ARE FAMILIAR WITH THE NEW TECHNIQUES. THE SCHEDULING SHOULD PROVIDE BLANKS FOR EMERGENCIES AND FOR FITTING IN PLANES DELAYED IN DEPARTURE FROM OTHER FIELDS. AIRPORT RULES SHOULD REQUIRE EVERY APPROACH ON RUNWAY 28 AND 19 TO BE A SIMULATED INSTRUMENT APPROACH FROM THE FIRST RADIO CONTACT WITH THE TOWER UNTIL THE TOUCHDOWN, SO THAT THE PILOTS AND THE TOWER OPERATORS WILL BUILD UP A BODY OF EXPERIENCE UPON WHICH THEY CAN DRAW WHEN INSTRUMENT CONDITIONS ACTUALLY DEVELOP.

IF SCHEDULES ARE PROPERLY SPACED, IF ALL PERSONS CONCERNED WITH ALL-WEATHER OPERATION ARE KEPT FULLY TRAINED, AND IF ALL AIRPORT AND PLANE EQUIPMENT IS ADEQUATELY MAINTAINED, THERE WILL BE NO STACKING PROBLEM IN BAD WEATHER DOWN TO THE ESTABLISHED MINIMUM. IF FIDO IS USED, THERE SHOULD BE, IN EFFECT, NO MINIMUM, AND NO SCHEDULE UNRELIABILITY.

## EXPEDITING GROUND TRAFFIC

SCHEDULES ARE NOT COMPLETED UNTIL THE PLANE ARRIVES AT THE TERMINAL. IN ALL-WEATHER OPERATIONS IT WILL OFTEN HAPPEN THAT VISIBILITY ALONG THE GROUND IS RESTRICTED SERIOUSLY ENOUGH TO MAKE TAXIING A PROBLEM. THE RUNWAY MUST BE CLEARED IMMEDIATELY FOR THE NEXT LANDING OPERATION, AND THE AIRCRAFT MUST BE GUIDED QUICKLY TO ITS RAMP. LIKEWISE, DEPARTING AIRCRAFT MUST REACH THE TAKEOFF POINT WITHOUT DELAY, AND WITHOUT DANGER OF INTERFERING WITH PLANES COMING IN FOR A LANDING. A MISTAKE AT ANY POINT

IN THE GROUND SEQUENCE MEANS PASSENGER ANNOYANCE AT BEST, AND, AT WORST, A PROGRESSIVE DISRUPTION OF OPERATIONS. IT HAS, THEREFORE, BEEN CONSIDERED ESSENTIAL TO DISCUSS TAXIWAY MARKING (UNDER AIRPORT LIGHTING) AND TO RECOMMEND HIGH INTENSITY TAXIWAY MARKERS AS A NECESSARY PART OF THE INTEGRATED LANDING AIDS SYSTEM.

## ALTERNATIVES

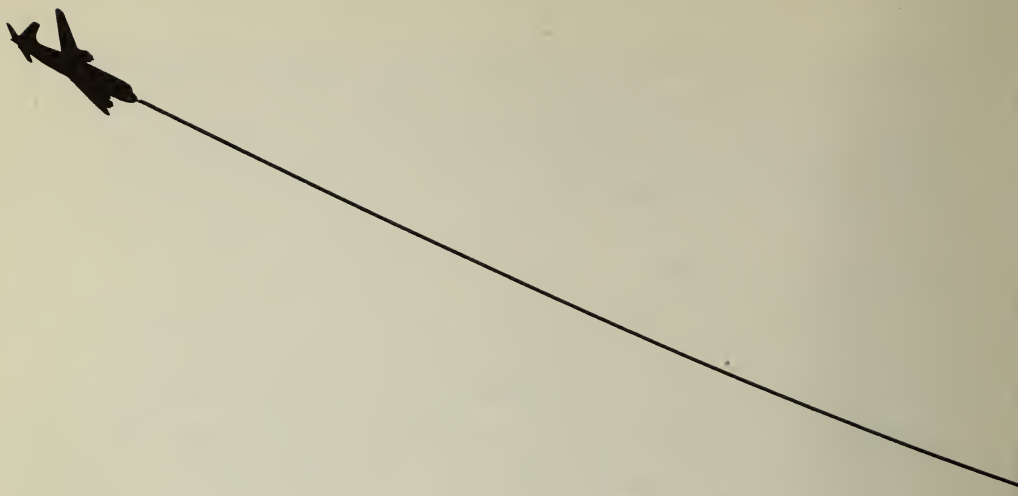
IF IT SHOULD NOT PROVE POSSIBLE TO INSTALL A TRUE ALL-WEATHER LANDING AIDS SYSTEM, SAN FRANCISCO'S WEATHER HISTORY WILL INEVITABLY CONTROL TO A CONSIDERABLE DEGREE THE SCHEDULING OF TRAFFIC AT SAN FRANCISCO AIRPORT. DISREGARDING ALL-WEATHER FLYING AIDS FOR A MOMENT, INSOFAR AS PUBLIC DEMAND PERMITS, SOME TRAFFIC MIGHT BE ADJUSTED TO FIT THE ANNUAL AND DIURNAL WEATHER CYCLES. THUS, IT IS DESIRABLE THAT FEWER ARRIVALS AND DEPARTURES BE SCHEDULED FOR THE HOURS 0000 TO 0900 WHEN FOG IS MOST LIKELY TO INTERRUPT THEM. LIKEWISE, CONFERENCES WITH AIRLINE TRAFFIC OFFICIALS AND A SYSTEMATIC STUDY OF PUBLIC NEEDS MIGHT PERMIT SOME ANNUAL SHIFTING OF THE DAILY DEPARTURE TIMES SO THAT FEWER OPERATIONS WOULD BE SET UP FOR THE CRITICAL FOG HOURS DURING THE WINTER FOG MONTHS.

IN TIME IT MAY BECOME NECESSARY TO ACCEPT NON-SCHEDULED OPERATIONS ONLY IN SLACK PERIODS OF THE DAY. SUCH A SCHEDULING PRINCIPLE MAY BE OBJECTIONABLE TO INDIVIDUALS AND MAY EVEN SEEM OVERCAUTIOUS DURING EXTENDED PERIODS OF GOOD WEATHER. NEVERTHELESS, THE NUMBER OF PLANES EXPECTED SHOULD NOT BE ALLOWED TO EXCEED THE HANDLING CAPACITY OF THE FIELD, AND THE CAPACITY SHOULD BE LOOKED UPON AS THE RATE WHICH PLANES CAN BE SAFELY HANDLED IN MINIMUM WEATHER CONDITIONS. AS LONG AS THE

CONTINUED POSSIBILITY REMAINS THAT EXTENDED PERIODS OF "CLOSED" WEATHER WILL OCCUR, THE CAPACITY OF THE FIELD MUST BE REGARDED AS CONSIDERABLY LESS THAN THE 30 PLANES PER HOUR THEORETICALLY POSSIBLE WITH ALL-WEATHER LANDING AIDS.

## A Word of Caution

AT THE RISK OF REPETITION, WE MUST CONTINUOUSLY EMPHASIZE THAT ANY SYSTEM OF AIDS IS EFFECTIVE ONLY TO THE EXTENT THAT IT IS USED BY FULLY-TRAINED PILOTS AND OPERATED AND MAINTAINED BY COMPETENT, FULLY-TRAINED GROUND PERSONNEL. EACH STEP IN THE DEVELOPMENT OF ALL-WEATHER FLYING MUST BE CAREFULLY PREPARED FOR, AND MUST BE CONTINUOUSLY CHECKED ON AFTER IT IS TAKEN. A PROCEDURAL MANUAL SHOULD BE PREPARED FOR TRAINING ALL PARTICIPATING PERSONNEL, INCLUDING THE PILOTS WHO WILL USE THE SYSTEM. GROUND PERSONNEL SHOULD CONDUCT SIMULATED OPERATIONS PERIODICALLY OF THOSE AIDS NOT USED DURING CLEAR WEATHER.



# SECTION 3.

THE LACK OF ADEQUATE LANDING AIDS IS RECOGNIZED TO BE A MAJOR BOTTLENECK IN ALL-WEATHER FLYING. A NUMBER OF AIDS OF VARIOUS KINDS HAVE BEEN PROPOSED, OR ACTUALLY DEVELOPED, FOR FACILITATING LANDING AND TAKE-OFF IN BAD WEATHER. THESE AIDS HAVE, IN SOME CASES, BEEN GIVEN EXAGGERATED PUBLICITY, AND, AS A GENERAL RULE, ARE NOT WELL-ENOUGH UNDERSTOOD TO PERMIT INTELLIGENT EVALUATION AND PROPER SELECTION. THE LANDING AIDS SECTION DESCRIBES IN GENERAL TERMS THE AIDS WHICH ARE BELIEVED TO BE ESSENTIAL TO ACHIEVE FULL USAGE OF THE SAN FRANCISCO INTERNATIONAL AIRPORT.

# LANDING AIDS

ELECTRONIC AIDS
AIRPORT LIGHTING
FOG DISPERSAL

# ELECTRONIC AIDS

Electronic equipment which should be considered for installation at the San Francisco International Airport falls into two classifications: (1) aids whose immediate installation is desirable for facilitation of present traffic, and (2) aids which should be considered for installation when the present expansion and reconstruction program is nearing completion. In considering the various aids, it is desirable to plan installations which can readily be shifted to new locations when the new runways come into use. It is also desirable to give preference to devices which, besides present usefulness, have the potential of inclusion in the air traffic control systems being developed for the future, such as Teleran and Navar.

## Aids Suitable for Immediate Installation

### Instrument Landing System

The Instrument Landing System now in operation at the airport will be the basic low approach aid for the immediate future. This equipment is installed and maintained by the CAA, and would not require discussion here if it were not for the runway construction program. This program will necessitate removal of the localizer and glidepath transmitters to the new locations serving instrument Runway 28L. While construction is in progress, problems of course stability are likely to occur, particularly with the localizer. Also, unless the final permanent site is carefully selected, deviations may continue to give trouble in the future. With proper care, these can be minimized or altogether avoided. Our suggestions in the matter of selecting a location will appear under recommendations.

## Compass Locator Stations

The compass locator is a low-frequency radio transmitter which emits an essentially omni-directional signal. This type of station gives properly equipped aircraft a navigational "fix" by reference to which the pilot can choose an appropriate heading. The Automatic Direction Finder (A.D.F.) receiving equipment of the aircraft shows the bearing of the compass locator with respect to the aircraft heading directly on a compass indicator. The ground location of the compass locator being received is determined by the pilot from a coded aural signal delivered to his headset.

Commercial carriers are more and more being equipped with dual ADF, in which the outputs of the two receivers operate separate pointers on a common axis in a radio compass indicator. This arrangement allows the two receivers to be tuned either to two different transmitters or to the same station. Two stations permit the pilot or navigator to quickly establish his position in respect to the location of the compass locator stations.

When two compass locator transmitters are placed on centerline at the ends of a landing runway equipped with ILS, they serve as an additional check on the dependability of the ILS localizer course.

They are particularly valuable, however, for use in making a low approach to a runway not equipped with ILS, because they can perform the function of the ILS localizer in setting up a longitudinal course along the axis. When ADF is used with the altimeter and rate of descent indicator, a descent can be safely and easily made through an overcast to an altitude of 200 feet above the terrain. Since a non-instrument runway is used only with a relatively high ceiling, the compass locator makes a satisfactory electronic low approach aid in marginal visibility conditions. The plane drops

OUT OF THE OVERCAST APPROXIMATELY ALIGNED WITH THE RUNWAY CENTERLINE AND IN SIGHT OF THE APPROACH AND/OR RUNWAY LIGHTS; PROVIDED, OF COURSE, THE DESCENT HAS BEEN PROPERLY TIMED.

COMPASS LOCATORS GIVE THE PILOT THE NAVIGATIONAL INFORMATION HE NEEDS TO EXECUTE A COMPLETELY INDEPENDENT PATTERN AND LOW APPROACH FROM THE TIME HE ENTERS THE RANGE OF THE TRANSMITTERS UNTIL HE REACHES THE LAST STAGES OF THE FINAL APPROACH.

### VHF Direction Finder

THE VERY HIGH FREQUENCY (VHF) DIRECTION FINDER IS AN ELECTRONIC DEVICE USED IN AN AIRPORT TOWER TO DETERMINE THE BEARING WITH RESPECT TO THE TOWER OF AIRCRAFT EQUIPPED WITH VHF TRANSMITTERS. IT PRESENTS AIRCRAFT DIRECTION ON AN OSCILLOSCOPE READABLE IN DAYLIGHT. THE AIRCRAFT OPERATES ITS VHF TRANSMITTER BRIEFLY WHILE THE GROUND OBSERVER TUNES IN, THEN THE DIRECTION OF THE PLANE CAN BE READ DIRECTLY OFF THE COMPASS ROSE SURROUNDING THE OSCILLOSCOPE. THE DEVICE PERMITS A TOWER OPERATOR FAMILIAR WITH LOCAL TERRAIN TO DIRECT THE PILOT INTO SOME GENERAL AREA WHERE LETDOWN THROUGH OVERCAST CAN SAFELY BE UNDERTAKEN.

IN INCLEMENT WEATHER IT MAY HAPPEN THAT THE VHF TRANSMITTING AND RECEIVING EQUIPMENT IS THE ONLY ELECTRONIC EQUIPMENT LEFT OPERATIVE IN A PLANE. IN SUCH AN EMERGENCY THE TOWER OPERATOR, USING ONLY THE VHF DIRECTION FINDER, MAY BE ABLE TO DIRECT THE PLANE TO SAFETY.

### Aids Suitable for Later Installation

THE SECOND PHASE OF THE DEVELOPMENT OF SAN FRANCISCO INTERNATIONAL AIRPORT WILL BEGIN WITH COMPLETION OF THE PRESENT EXPANSION PROGRAM ABOUT 1950. AT THAT TIME IT WILL BE WISE TO RECONSIDER THE ELECTRONIC EQUIP-

MENT IN USE AND DESIRABLE IN THE LIGHT OF PROGRESS MADE DURING THE INTERVENING YEARS. AT THAT TIME, IN PARTICULAR, ELECTRONIC TRAFFIC CONTROL DEVICES WILL DOUBTLESS HAVE REACHED AN ADVANCED STAGE OF PERFECTION FOR COMMERCIAL USE. MOREOVER, THE EXPERIENCE OF PILOTS USING THE AIRPORT WILL HAVE RISEN TO A LEVEL WHERE THEY CAN BEGIN ADOPTING PRECISION APPROACH AND LANDING PROCEDURES. IT IS ALSO QUITE PROBABLE THAT THE INCREASE OF TRAFFIC INTO AND OUT OF SAN FRANCISCO WILL, BY THAT TIME, MAKE AREA TRAFFIC CONTROL HIGHLY DESIRABLE, IF NOT ESSENTIAL.

TRAFFIC CONTROL METHODS IN PROCESS OF DEVELOPMENT ALL CONTEMPLATE THE GENERAL USE OF RADAR, POSSIBLY EXTENDING INTO THE FINAL APPROACH AND LANDING TECHNIQUE. THE FOLLOWING DEVICES ARE CERTAIN TO BE REQUIRED AS A PART OF THE FUTURE AIR NAVIGATION AND CONTROL SYSTEMS:

### SEARCH RADAR

IT WILL BE ESSENTIAL AT ANY BUSY FIELD THAT THE CONTROL TOWER HAVE A SEARCH RADAR UNIT CAPABLE OF SCANNING THE SKY OVER A 50 MILE RADIUS, OR MORE, AND OF REVEALING THE LOCATION OF ALL PLANES IN THE AREA, AND THEIR LATERAL SEPARATION IN RESPECT TO ONE ANOTHER. THE INFORMATION THUS OBTAINED SHOULD BE PRESENTED ON AN ADVANCED TYPE OF PPI (PLANE POSITION INDICATOR) OSCILLOSCOPE, 12 INCHES OR MORE IN DIAMETER. THESE SCOPES SHOULD BE READABLE IN DAYLIGHT, SO THAT TRAFFIC INFORMATION MAY BE EXCHANGED AMONG TOWER PERSONNEL WITHOUT TELECOMMUNICATION TO A DARKENED RADAR ROOM. EQUIPMENT MEETING THESE SPECIFICATIONS IS BEING DEVELOPED AT THE PRESENT TIME, AND SHOULD BE READILY AVAILABLE BY THE TIME SAN FRANCISCO AIRPORT NEEDS IT.

### HEIGHT-FINDING RADAR

THIS RADAR DEVICE IS A COMPANION TO THE SEARCH RADAR. IT WILL BE ABLE TO MEASURE THE ALTITUDE OF ANY PLANE WITHIN 50 MILES AND FROM GROUND LEVEL TO 20,000 FEET. THUS, THE TOWER WILL KNOW THE ALTITUDE AS WELL

AS THE LOCATION OF EVERY PLANE IN THE VICINITY, AND CAN MAINTAIN ADEQUATE SEPARATION OF TRAFFIC.

USED TOGETHER, THE SEARCH AND HEIGHT FINDING RADAR WILL PROVIDE A MEANS FOR DIRECTING AIRCRAFT NOT EQUIPPED FOR ILS OPERATIONS DOWN THROUGH AN OVERCAST TO CONTACT LANDING ELEVATIONS. THEY ALSO PROVIDE THE TOWER WITH A MEANS OF CHECKING THE ILS COURSES.

GROUND CONTROL APPROACH

GCA DIFFERS FROM THE RADAR DEVICES ABOVE IN BEING DESIGNED TO DIRECT THE COMPLETE APPROACH OF AN AIRCRAFT FROM THE TIME IT NEARS THE FIELD UNTIL IT TOUCHES DOWN ON THE RUNWAY. THE DEVICES NOW IN USE COMBINE TWO SEARCH RADAR SCOPES WITH FOUR PRECISION AZIMUTH AND ALTITUDE SCOPES TO COVER ALL PARTS OF THE FINAL APPROACH. THE MILITARY VERSION USED DURING THE WAR REQUIRES 5 HIGHLY TRAINED OPERATORS CONTINUOUSLY ON DUTY IN ADDITION TO COMPETENT MAINTENANCE PERSONNEL. THIS CREW IS TOO LARGE A STAFF FOR A MUNICIPAL AIRPORT TO PROVIDE WHEN IT IS CONSIDERED THAT 4 COMPLETE CREWS OF OPERATORS AND MAINTENANCE PERSONNEL MUST BE AVAILABLE TO KEEP THE GCA EQUIPMENT OPERATING 24 HOURS A DAY, 7 DAYS A WEEK. AT PRESENT THE CAA AND OTHER AGENCIES ARE TESTING MODIFICATIONS OF THE MILITARY UNIT IN WHICH THE INDICATORS HAVE BEEN REMOTED TO THE AIRPORT TOWER. THE PRESENTATION OF INFORMATION HAS BEEN CONSOLIDATED SO THAT ONLY TWO OSCILLOSCOPES ARE REQUIRED TO COVER THE SEARCH PATTERN AND THE PRECISION GLIDEPATH, AS COMPARED WITH 6 OSCILLOSCOPES IN THE UNMODIFIED MILITARY DEVICE. TWO OPERATORS HANDLE THE ENTIRE PROCESS. BEFORE LONG THESE EXPERIMENTS SHOULD BRING OUT MUCH SIMPLER RADAR DEVICES FOR PRECISELY DIRECTING THE COMPLETE FINAL APPROACH TO TOUCHDOWN. AT THAT TIME IT IS URGED THAT ARRANGEMENTS BE MADE WITH THE CAA TO EXPEDITE THE INSTALLATION OF SUCH A UNIT AT SAN FRANCISCO, FOR THE USE OF PLANES NOT EQUIPPED WITH ILS, AND FOR MONITORING ILS APPROACHES, ESPECIALLY DURING HEAVY TRAFFIC PERIODS.

Power requirements for any future GCA equipment will not exceed 100 amperes at 117 volts, the requirement for the present military version; in fact, they should be less, since the search function will be assigned to the tower radar, and power supplies to the precision unit on the field will thereby be reduced.

### Radar Beacons

The radar beacon is a navigational device used in connection with airborne search radar. By means of beacons, the pilot can determine the exact map location of his plane when flying through or above an unbroken cloud layer. The airborne search unit presents the pilot with a map of the terrain below. Any radar beacons located within the airborne scan appear on the map as points of light, and the pilot can set a course by reference to them. When the beacon intercepts the signal from the airborne search unit, it instantly transmits a coded identification from which the pilot can identify the beacon; also, he can determine the distance and bearing to the identified radar beacon. Two beacons aligned along the extended runway centerline provide an adequate low approach aid. Although airborne search radar has not yet become common on civilian aircraft, the more progressive airlines are adopting it, and it is likely to become universal in a short time. It is badly needed on all large civilian aircraft.

### The Long View

The present status of Teleran, Navar and related proposals for aircraft navigation and control is not well enough established to be included in this study. It is to be pointed out that many of the devices discussed herein will in many cases be suitable for inclusion in the new systems and will not, therefore, become obsolete.

For use in low visibility conditions, the design of airport lighting is predicated on the use of electronic low approach aids to guide aircraft as far as the middle marker on their final approach; that is, to a point approximately 3500 feet from the runway. At this point, the plane should be not more than 300 feet off the approach centerline, nor more than 100 feet below or 200 feet above the correct glidepath. Practiced instrument pilots normally achieve better than this degree of precision in following ILS. From the middle marker to the runway continuous visual guidance is desirable, by means of which the pilot can determine the runway axis, line his plane up with it, and gauge his attitude, altitude, and progress toward the threshold.

## Approach Lights

For types of aircraft now in service, the only satisfactory visual indication of correct heading in low visibility is given by level rows of lights paralleling the approach, alongside which the pilot aligns his plane. Two rows offset symmetrically from the axis will adequately define its location for the last approach stage. Two rows will also provide an external ground plane from which the pilot can estimate attitude, altitude and longitudinal progress to the extent that the rows are visible in the field of view permitted by the cockpit structure ("cockpit cutoff") through the prevailing atmospheric condition. A minimum of three lights per row is considered necessary for such judgements.

The interim standard approach light system recently adopted by the Approach Light Evaluation Subcommittee of the Aeronautical Board recommends the installation of two light rows parallel with the axis and offset 100 to 125

FEET LEFT AND RIGHT OF THE AXIS. THE ROWS MUST EXTEND FROM THE THRESHOLD TO A POINT 3000 FEET OUT IN THE APPROACH. LIGHTS ARE TO BE SPACED 100 TO 200 FEET APART ALONG THE ROWS. TO DISTINGUISH THE ROWS, THE UNITS ON THE PILOT'S LEFT ARE TO BE RED, THOSE ON HIS RIGHT AMBER. AT CIVILIAN AIRPORTS, THE LEFT ROW OF THIS SYSTEM MAY BE INSTALLED ALONE, BUT THIS IS DEFINITELY NOT RECOMMENDED, INASMUCH AS IT LARGELY ELIMINATES THE POSSIBILITY OF ESTIMATING ATTITUDE AND ALTITUDE BY WATCHING THE LIGHTS. ALSO, IT DECREASES THE GUIDANCE AVAILABLE TO PILOTS APPROACHING OFF THE CORRECT GLIDEPATH.

ANOTHER CONFIGURATION, THE CAA SLOPE-LINE SYSTEM, DESIGNED ON GEOMETRIC PRINCIPLES TO SHOW THE PILOT THE EXACT LOCATION OF THE CORRECT GLIDEPATH, IS TO BE TESTED THIS YEAR. SINCE ITS EFFECTIVENESS IN FOG HAS NOT YET BEEN ESTABLISHED, IT CANNOT BE RECOMMENDED AT THIS TIME. HOWEVER, IT SHOULD BE KEPT IN MIND.

FOR INSTALLATION ON THE PARALLEL ROW SYSTEM, TWO MAIN TYPES OF LIGHT UNITS ARE AVAILABLE: THOSE USING INCANDESCENT LAMPS, AND A NEW TYPE IN WHICH LIGHT IS OBTAINED FROM AN ELECTRICAL DISCHARGE THROUGH KRYPTON GAS. THE LATTER UNITS HAVE NOT AS YET BEEN ADEQUATELY TESTED IN LOW VISIBILITY CONDITIONS, AND THEIR USEFULNESS IS UNDETERMINED. THEORETICALLY, THEY SHOULD BE VERY EFFECTIVE IN FOG; THEREFORE, GASEOUS DISCHARGE LIGHTS SHOULD ALSO BE KEPT IN MIND UNTIL TESTS SCHEDULED FOR THIS SUMMER HAVE BEEN PERFORMED. GASEOUS DISCHARGE APPROACH LIGHTS WILL BE MORE EXPENSIVE TO BUY AND INSTALL THAN PRESENT TYPES.

THE CONVENTIONAL INCANDESCENT TYPE OF LIGHT HAS BEEN TESTED AND PROVED TO BE ADEQUATE AT 1/2 MILE DAYLIGHT OBJECT VISIBILITY, AND BELOW, AFTER PILOTS HAVE BECOME FULLY EXPERIENCED IN ITS USE. A WIDE BEAM OF

RECTANGULAR DISTRIBUTION HAS BEEN FOUND TO BE THE MOST DESIRABLE. WIDE-BEAM LIGHTS, WITH A PEAK CANDLEPOWER OF NOT LESS THAN 100,000 (CLEAR) AND HAVING A DIVERGENCE OF 30 TO 40 DEGREES WITHIN WHICH THE CANDLEPOWER IS UNIFORM AND DOES NOT DROP BELOW 3/5 OF THE PEAK VALUE, HAVE BEEN SUCCESSFULLY FLOWN IN CONDITIONS OF LESS THAN 1/8 MILE VISIBILITY AND 100-FOOT CEILING.

THE VALUE OF THE WIDE-BEAM SPREAD LIES IN THE FACT THAT SUCH UNITS ARE VISIBLE THROUGHOUT VERY LARGE VERTICAL PLANES IN THE APPROACH AREA, OUTSIDE OF, AND OVER THE LIGHTING SYSTEM. THE FULL GUIDANCE VALUE OF THE LIGHTING SYSTEM IS THEREBY MADE AVAILABLE BOTH TO PILOTS FLYING THE CORRECT GLIDEPATH AND TO THOSE WHO, FOR VARIOUS REASONS, ENTER THE APPROACH AREA ABOVE, BELOW, OR TO EITHER SIDE OF THE CORRECT GLIDEPATH.

## "STUB" APPROACH LIGHT SYSTEM

AT AIRPORTS WHERE VERY LOW CEILINGS AND VISIBILITIES RARELY OCCUR, AND ON RUNWAYS USED ONLY IN MARGINAL VISIBILITY CONDITIONS, THE FULL 3000-FOOT APPROACH LIGHT CONFIGURATION IS NOT REQUIRED. IN SUCH CASES, "STUB" APPROACH LIGHT SYSTEMS ARE RECOMMENDED. THESE SYSTEMS ARE IN ALL RESPECTS IDENTICAL WITH THE FULL CONFIGURATION EXCEPT THAT THEY EXTEND ONLY 1000 FEET INTO THE APPROACH FROM THE RUNWAY THRESHOLD. THE MAXIMUM ALLOWABLE LIGHT SPACING, 200 FEET APART ALONG THE ROWS, IS DESIRABLE FOR THESE SYSTEMS.

## RUNWAY MARKER LIGHTS

THE WIDE-BEAM PRINCIPLE APPLIES TO RUNWAY MARKERS AS WELL AS APPROACH LIGHTS, ALTHOUGH THE REQUIRED DIVERGENCE IS MUCH SMALLER. A PLANE ON CENTERLINE SHOULD CROSS THE MARGIN INTO THE MAIN BEAM ABOUT 4000 FEET FROM ANY LIGHT CONSIDERED, AND SHOULD FLY CONTINUOUSLY IN THE MAIN BEAM UNTIL IT REACHES A POINT ABOUT 500 FEET FROM

THE LIGHT CONSIDERED. THIS REQUIRES A UNIFORM BEAM 9 - 10 DEGREES WIDE, THE OUTER EDGE OF WHICH IS ALIGNED APPROXIMATELY WITH THE RUNWAY MARGIN. THE DIVERGENCE IN THE VERTICAL PLANE SHOULD BE EQUAL TO THE HORIZONTAL SPREAD, TO COVER ALL POSSIBLE ANGLES OF DESCENT, YET NOT BLIND THE PILOT DURING HIS TOUCHDOWN AND ROLL UNDER NIGHT CONDITIONS. WITHIN THIS SPREAD THE CANDLEPOWER SHOULD NOT BE LESS THAN 20,000. GREATER VALUES ARE DESIRABLE FOR DAYLIGHT USE.

A BEAM OF THIS TYPE CAN BE OF CONICAL SHAPE FOR THE SAKE OF ECONOMY, SUCH AS IS PRODUCED BY A PROPERLY LOCATED LIGHT SOURCE BEHIND A SINGLE CONCENTRIC CONDENSER LENS. PROVISION MUST, OF COURSE, BE MADE FOR FOLLOWING THE ANC STANDARD COLOR SEQUENCE. THIS PROVISION SHOULD ALLOW FOR POSSIBLE FUTURE CHANGES IN THE SEQUENCE.

IN ADDITION TO DISTINCTIVELY MARKING THE RUNWAY FOR APPROACHES FROM EITHER END, THE MARKERS SHOULD PROVIDE DIRECT BEAMS UPWARD AND TO THE SIDE FOR THE GUIDANCE OF PLANES CIRCLING THE FIELD IN CLEAR WEATHER OR BELOW AN OVERCAST. BI-DIRECTIONAL LIGHTS WITH ADDITIONAL SIDE AND ZENITH LENSES ARE SATISFACTORY FOR THIS PURPOSE, PROVIDED THE LAMPS USED HAVE AN ADEQUATE LUMEN OUTPUT TO PROVIDE THE MAIN BEAM CANDLEPOWER SUGGESTED ABOVE.

## BRIGHTNESS CONTROLS

THE CANDLEPOWERS RECOMMENDED FOR BOTH APPROACH AND RUNWAY LIGHTS ARE MINIMUM ESSENTIALS FOR DAYLIGHT OPERATIONS. AT NIGHT, WHEN BACKGROUND BRIGHTNESS IS A VERY SMALL FRACTION OF THE DAYLIGHT VALUES, LOWER CANDLEPOWER WILL ACCOMPLISH THE SAME PURPOSES. ALSO, AT NIGHT THE PILOT IS MORE OR LESS DARK ADAPTED, SO THAT FULL BRIGHTNESS MIGHT CREATE A BLINDING GLARE. IT IS, THEREFORE, NECESSARY TO PROVIDE BRIGHTNESS CONTROLS FOR EVENING AND NIGHT OPERATIONS. THE STANDARD REGULATORS USED FOR THIS PURPOSE PERMIT BRIGHTNESS TO BE VARIED IN THE

FOLLOWING STEPS: 1%, 3%, 10%, 30%, AND 100%. THESE INTERVALS ARE SATISFACTORY FOR USE WITH THE APPROACH AND RUNWAY LIGHTS SUGGESTED. IF UNITS WITH ADDITIONAL CANDLEPOWER ARE OBTAINED, IT MAY BE NECESSARY TO PROVIDE REGULATORS WITH LARGER BRIGHTNESS INTERVALS, CAPABLE OF REDUCING THE LIGHTS ON CLEAR NIGHTS TO A CANDLEPOWER WHICH WILL NOT CAUSE GLARE.

## TAXIWAY LIGHTING

IT HAS NOT BEEN THE PRACTICE IN THE PAST TO USE LIGHTS OF HIGH CANDLEPOWER FOR TAXIWAY MARKING, SINCE AIRCRAFT OPERATIONS HAVE BEEN RESTRICTED TO CONDITIONS IN WHICH GROUND LEVEL VISIBILITY IS TOO GOOD TO REQUIRE THEM. HOWEVER, FUTURE OPERATIONS WILL BE CONDUCTED IN CONDITIONS WHICH WILL SERIOUSLY RESTRICT VISIBILITY ALONG THE GROUND. THIS IS PARTICULARLY TRUE IF FIDO IS TO BE USED, SINCE THE BURNERS WILL NOT INCREASE VISIBILITY IN THE UPWIND AREA, AND WILL NOT NECESSARILY CLEAR THE SURFACE LAYER DOWNWIND OF THE RUNWAY. OBVIOUSLY, THERE IS LITTLE TO BE GAINED IF PLANES ARE BROUGHT DOWN BY FIDO BUT ARE UNABLE TO TAXI TO THE RAMP.

SAN FRANCISCO, IN PLANNING FOR ALL-WEATHER OPERATION, SHOULD CONSIDER THE POSSIBILITY THAT A PLANE TAXIING TO OR FROM THE RUNWAY WILL HAVE TO TRAVEL LONG DISTANCES THROUGH FOGS LYING ON THE SURFACE, WHICH MAY RESTRICT THE PILOT'S VISIBILITY TO 1/16 MILE OR LESS AHEAD OF THE PLANE. UNDER THESE CIRCUMSTANCES TAXI LIGHTS OF GREATER CANDLEPOWER THAN THOSE NOW IN USE WILL BE REQUIRED TO PENETRATE THE FOG AND MARK OUT THE PATH AHEAD.

THE STANDARD COLOR OF TAXI LIGHTS IS BLUE; FILTERS OF THIS COLOR REDUCE THE EFFECTIVE LIGHT OUTPUT OF INCANDESCENT LAMPS TO ABOUT 1/10 THE UNFILTERED VALUE. INCANDESCENT LIGHTS USED FOR THE PURPOSE WILL, THEREFORE,

HAVE TO HAVE VERY HIGH INITIAL VALUES TO EFFECTIVELY PENETRATE A DENSE FOG. POINT SOURCES OF LIGHT, WHICH ARE NECESSARILY OF THE INCANDESCENT DESIGN, ARE CONSIDERED TO BE THE MOST EFFECTIVE FOR FOG PENETRATION.

LOOKING AHEAD, IT WOULD BE DESIRABLE TO MAKE PLANS NOW FOR A TAXIWAY LIGHTING INSTALLATION WHOSE LIGHTS WILL BE VISIBLE AT LEAST 400 - 600 FEET AHEAD OF THE TAXIING PLANE IN THE DENSEST POSSIBLE FOG. TO OBTAIN THIS VISUAL RANGE WILL REQUIRE UNFILTERED CANDLEPOWERS ON THE ORDER OF 20,000, OR APPROXIMATELY THE SAME AS THE RUNWAY LIGHTS. THESE RANGES WILL GIVE ADEQUATE ADVANCE NOTICE OF TURNS FOR THE PILOT OF LARGE AIRCRAFT WHICH ARE DIFFICULT TO MANEUVER ON THE GROUND, AND WILL ALSO ESTABLISH A DEPENDABLE LINE OF LIGHTS AHEAD FOR RAPID MOVEMENT ALONG STRAIGHT SECTIONS.

THE NECESSARY CANDLEPOWER DISTRIBUTION FOR TAXI LIGHTS IS PRACTICALLY THE SAME AS FOR RUNWAY LIGHTS; AND, AS WITH THE RUNWAY LIGHTS, INTENSITY CONTROLS WILL BE NEEDED TO REDUCE THEIR BRILLIANCE AT NIGHT.

FIDO IS A METHOD OF REMOVING FOG FROM THE RUNWAY AREAS OF AIRPORTS. THE INITIAL DEVELOPMENT WORK WHICH MADE FIDO A PRACTICAL DEVICE FOR CONTROLLING TERMINAL WEATHER WAS UNDERTAKEN BY BRITISH AND AMERICAN SCIENTISTS DURING THE WAR TO FACILITATE THE CONTINUOUS OPERATION OF MILITARY AIRCRAFT OVER THE CONTINENT. THE ONLY PROVEN METHOD OF DISPERSING FOG IS BY THERMAL MEANS AND CONSISTS OF SUPPLYING ENOUGH HEAT TO THE AIR OVER THE RUNWAY TO EVAPORATE THE DROPLETS OF LIQUID WATER WHICH CONSTITUTE A FOG. THE REMOVAL OF THESE FOG PARTICLES BRINGS ABOUT AN INCREASE IN THE CEILING AND VISIBILITY. OTHER METHODS OF DISPERSING FOG HAVE BEEN TRIED ON A FIELD TEST SCALE WITH VARYING DEGREES OF SUCCESS. HOWEVER, NONE OF THE OTHER METHODS ARE AS EFFICIENT, PRACTICAL, ECONOMICAL, AND/OR GENERALLY ACCEPTABLE AS THE THERMAL PROCESS.

FIDO IS A SPECIFIC REMEDY FOR AIRPORTS HAMPERED BY FREQUENT FOGS. IT WILL NOT IMPROVE THE VISIBILITY DURING RAIN, SNOW, OR DUST STORMS, NOR REMOVE SMOKE FROM THE ATMOSPHERE. FOG, HOWEVER, IS THE CAUSE OF NEARLY ALL THE INTERRUPTIONS IN AIRCRAFT OPERATION AT SAN FRANCISCO. A FOG DISPERSAL INSTALLATION WHICH WILL ALLOW AIRLINES TO SCHEDULE OPERATIONS TO AND FROM SAN FRANCISCO REGARDLESS OF FOG WILL PERMIT THEM TO PROMISE THE PUBLIC THE SAME SCHEDULE RELIABILITY AS SURFACE TRANSPORTATION. A FIDO INSTALLATION IS RELATIVELY EXPENSIVE WHEN COMPARED WITH OTHER TYPES OF LANDING AIDS. HOWEVER, THE OUT-OF-POCKET COST TO THE AIRLINES EACH YEAR RESULTING FROM CANCELLATIONS AT SAN FRANCISCO WOULD PAY FOR A FIDO INSTALLATION IN LESS THAN FIVE YEARS. THIS STATEMENT DOES NOT TAKE INTO ACCOUNT THE ADDITIONAL INCOME WHICH WOULD DERIVE TO THE AIRLINES IF THEY COULD OFFER SCHEDULE RELIABILITY.

A FOG DISPERSAL INSTALLATION IS USED ONLY WHEN OTHER LANDING AIDS ARE INSUFFICIENT TO EFFECT A LANDING; THAT IS, WHEN CEILING AND VISIBILITY ARE BELOW THE LEGAL MINIMUMS. FIDO IS USED AT SUCH TIMES TO ARTIFICIALLY CREATE MINIMUM CONDITIONS OVER THE RUNWAYS USED FOR LANDING AND TAKEOFF IN INSTRUMENT WEATHER. IT IS A LAST RESORT, AND WILL BE GRADUALLY SUPERSEDED WHEN THE IMPROVEMENT OF ELECTRONIC LANDING AIDS PERMITS MINIMUMS TO BE LOWERED AND EVENTUALLY DISCARDED.

THE ADDITION OF HEAT TO THE AIR OVER AN AIRPORT IS MOST READILY ACCOMPLISHED BY BURNING FUEL IN OPEN FLAMES ABOUT THE PERIMETER OF THE AREA TO BE CLEARED. THE LOCATION OF THE BURNERS RELATIVE TO THE RUNWAY AREA DEPENDS UPON THE WINDS ACCOMPANYING FOG. THE AMOUNT OF FUEL NECESSARY TO ACCOMPLISH THE CLEARANCE IS DEPENDENT UPON THE REQUIRED DIMENSIONS OF CLEARANCE, PARTICULARLY THE CEILING HEIGHT, THE WATER CONTENT OF THE FOG, AND THE WIND CONDITIONS ACCOMPANYING THE FOG. THE DESIGN OF FOG DISPERSAL SYSTEMS HAS BEEN EXHAUSTIVELY STUDIED IN WIND TUNNELS AND IN THE FIELD. THIS DATA HAS BEEN USED IN LAYING OUT THE FOG DISPERSAL INSTALLATION RECOMMENDED FOR THE SAN FRANCISCO AIRPORT.

WARTIME FIDO MADE USE OF LOW-PRESSURE BURNER INSTALLATIONS, CONSTRUCTED ON THE SAME PRINCIPLE AS GASOLINE STOVES AND LANTERNS, IN WHICH THE BURNER VAPORIZES ITS FUEL IN A PRE-HEATER DEVICE PRIOR TO BURNING IT IN THE OPEN AIR. RELATIVELY EXPENSIVE GASOLINE WAS THE ONLY FUEL WHICH COULD BE USED IN LOW-PRESSURE BURNERS. THEY REQUIRED A WASTEFUL FIVE TO TEN MINUTE PRE-HEATING PERIOD BEFORE DISPERSAL COULD BEGIN, DURING WHICH TIME A GREAT DEAL OF SMOKE WAS RELEASED INTO THE ATMOSPHERE.

CONTEMPORARY TYPES OF FIDO USE HIGH PRESSURE BURNERS MODIFIED FROM THOSE BUILT FOR INDUSTRIAL AND MARINE BOILERS. THE HIGH PRESSURE BURNER RECEIVES ITS FUEL AT A PRESSURE OF 1000 TO 1500 POUNDS PER SQUARE INCH. WHEN FUEL GOES THROUGH THE SPECIALLY DESIGNED NOZZLES AT THIS HIGH PRESSURE, IT IS ATOMIZED INTO A SPRAY OF MICROSCOPIC DROPLETS WHICH BURN SMOKELESSLY IN THE OPEN AIR. THIS BURNER DOES NOT NEED A PRE-HEAT PERIOD; IT ACHIEVES SMOKELESS COMBUSTION AS SOON AS THE FUEL IN THE BURNER LINE REACHES FULL PRESSURE, WHICH IS A MATTER OF SECONDS. THE SMOKELESS COMBUSTION OF THE HIGH PRESSURE BURNER ALLOWS FOG DISPERSAL TO TAKE PLACE MORE QUICKLY AND WITH LESS OF THE FUEL. ALSO, THESE BURNERS CAN OPERATE WITH HEAVIER, LESS EXPENSIVE FUELS, SUCH AS LIGHT DIESEL OR FURNACE OIL.

ADDITIONAL FEATURES OF MODERN FIDO ARE AUTOMATIC IGNITION, AND REMOTELY CONTROLLED VALVES AND PUMPS WHICH ALLOW A HIGH PRESSURE SYSTEM TO BE OPERATED WITH PRECISION. THE BURNING PERIOD CAN BE CAREFULLY COORDINATED WITH THE MOVEMENTS OF THE APPROACHING AIRCRAFT. THIS SYNCHRONIZATION PERMITS A FOG DISPERSAL SYSTEM TO BE OPERATED A MINIMUM LENGTH OF TIME WITH A MINIMUM FUEL EXPENDITURE.

THE MOST RECENT DEVELOPMENT IS THE VARIABLE CAPACITY HIGH PRESSURE BURNER. THESE BURNERS, WITH THEIR ASSOCIATED EQUIPMENT, PERMIT THE AMOUNT OF HEAT INTRODUCED INTO THE ATMOSPHERE TO BE VARIED OVER A RANGE OF 4 TO 1. WITH SUCH AN INSTALLATION, FIDO CAN BE ADJUSTED

TO PARTICULAR WEATHER CONDITIONS. FUEL CONSUMPTION CAN BE REDUCED IN LIGHT FOGS WITH NEAR-CALM WIND CONDITIONS, YET THE CAPACITY IS AVAILABLE FOR SUCCESSFULLY COMBATTING THE MORE SEVERE CONDITIONS WHICH OCCASIONALLY WILL OCCUR. VARIABLE CAPACITY BURNERS COST SOMEWHAT MORE THAN FIXED TYPES, BUT SHOULD SOON PAY FOR THEMSELVES IN REDUCED ANNUAL FUEL BILLS.

# ESTIMATED COST

It is estimated that a complete and well-integrated system of landing aids which would insure 100 per cent utilization of the airport, regardless of terminal weather conditions, will cost $1,092,500, or about 3 per cent of the value of the San Francisco International Airport. The total installation costs would, in all probability, be apportioned between Federal agencies and the City and County of San Francisco, as is indicated in Table 1.

Operational and maintenance costs to San Francisco for the recommended landing aids, including manpower, materials, fuels, etc., would run a minimum of $95,000 per year for the system (based on average annual incidence of fog). These costs are broken down in Table 2.

Table 3 analyzes the installation and operational costs on a yearly basis. Although many of the aids under consideration may still be in use ten years from now, there are items now in the research stage which may make obsolete some of the present aids in five to seven years, in spite of the time required for development, evaluation, standardization, production, and installation. It is, therefore, considered advisable to plan on amortization of the integrated system recommended in this report over a seven-year period.

Even with the outstanding efficiency which has marked the operation of the San Francisco International Airport in past years, it is probable that the recommended system could not be ready for operation until the winter of 1949-1950. Hence, amortization and operating costs are presented for a seven-year period, beginning with 1950.

# AND METHODS OF AMORTIZATION

TABLE I

ESTIMATED INITIAL COST OF INTEGRATED LANDING AIDS SYSTEM
SAN FRANCISCO INTERNATIONAL AIRPORT

CAA RESPONSIBILITY

| | | |
|---|---|---|
| ELECTRONIC AIDS | | |
| ILS | | $ 70,000.00 |
| GCA (WHEN APPROVED FOR USE BY CAA) | | 100,000.00 |
| SEARCH RADAR | | 50,000.00 |
| HEIGHT FINDER | | 50,000.00 |
| COMPASS LOCATORS (4) | | 10,000.00 |
| VHF DIRECTION FINDER | | 2,500.00 |
| | TOTAL | $282,500.00 |
| AIRPORT LIGHTING | | |
| 3000' APPROACH SYSTEM | | $ 75,000.00 |
| 1000' STUB APPROACH SYSTEM | | 35,000.00 |
| 1/2 OF RUNWAY LIGHTING | | 62,500.00 |
| 1/2 OF TAXIWAY LIGHTING | | 62,500.00 |
| | TOTAL | $235,000.00 |

TOTAL ESTIMATED INSTALLATION COST TO THE CAA: $ 517,500.00

MUNICIPAL RESPONSIBILITY

| | | |
|---|---|---|
| AIRPORT LIGHTING | | |
| 1/2 OF RUNWAY LIGHTING | | $ 62,500.00 |
| 1/2 OF TAXIWAY LIGHTING | | 62,500.00 |
| | TOTAL | $125,000.00 |
| FIDO (SUGGESTED MUNICIPAL RESPONSIBILITY) | | |
| INSTALLATION OF BASIC SYSTEM | | $450,000.00 |

TOTAL
ESTIMATED INSTALLATION COST TO SAN FRANCISCO: $ 575,000.00

ESTIMATED TOTAL COST OF ALL LANDING AIDS: $1,092,500.00

TABLE 2

## ESTIMATED ANNUAL OPERATING AND MAINTENANCE COSTS OF MUNICIPALLY OPERATED INTEGRATED LANDING AIDS SAN FRANCISCO INTERNATIONAL AIRPORT

### AIRPORT LIGHTING

| | | |
|---|---|---|
| LABOR | | $ 5,000.00 |
| RUNWAY LAMP REPLACEMENT | (100%) | 800.00 |
| RUNWAY UNIT REPLACEMENT | ( 10%) | 3,200.00 |
| APPROACH LAMP REPLACEMENT | (100%) | 1,700.00 |
| APPROACH UNIT REPLACEMENT | (1 UNIT) | 800.00 |
| POWER CONSUMPTION PER YEAR | | 2,000.00 |
| MISCELLANEOUS | | 1,500.00 |
| | TOTAL | $ 15,000.00 |

### F I D O

| | |
|---|---|
| LABOR | $ 30,000.00 |
| BURNER SYSTEM MAINTENANCE | 7,500.00 |
| DISTRIBUTION SYSTEM MAINTENANCE | 6,500.00 |
| MISCELLANEOUS | 1,000.00 |
| FUEL (BASED ON AVERAGE YEARLY WEATHER AND JANUARY 1948 SCHEDULING) | 35,000.00 |
| TOTAL | $ 80,000.00 |

ESTIMATED TOTAL YEARLY OPERATING COST OF ALL MUNICIPALLY OPERATED LANDING AIDS: $ 95,000.00

TABLE 3

YEARLY ANALYSIS OF LANDING AIDS COSTS

(FIGURES BASED ON AIDS COMING UNDER MUNICIPAL COGNIZANCE)

| | |
|---|---|
| ONE SEVENTH OF INSTALLATION COST PLUS INTEREST ON INVESTMENT AND MISCELLANEOUS COST | $ 85,000.00 |
| TWELVE MONTHS' AVERAGE OPERATING AND MAINTENANCE COSTS | $ 95,000.00 |
| TOTAL LANDING AIDS COST PER YEAR: | $180,000.00 |

THE $180,000 ANNUAL LANDING AIDS COST TO SAN FRANCISCO CAN BE AMORTIZED EITHER BY COLLECTING A DIRECT ANNUAL CHARGE FROM THE AIRLINES EQUAL TO THE COST OF THE LANDING AIDS ACTUALLY USED DURING THE YEAR, OR BY INCREASING THE MOVEMENT FEES TO ALL SCHEDULED AIRLINES ON A FLAT-RATE BASIS TO GUARANTEE ALL-WEATHER OPERATION.

IT APPEARS THAT THE SIMPLEST AND MOST ECONOMICAL ADMINISTRATIVE PROCEDURE WOULD BE TO SPREAD THE ESTIMATED ARRIVAL COST FOR LANDING AIDS OVER THE 60,000 YEARLY SCHEDULES. THIS WOULD INDICATE THAT THE MOVEMENT FEE SHOULD BE INCREASED ON THE BASIS OF $3.00 PER MOVEMENT. THIS AMOUNT, OF COURSE, WOULD BE MODIFIED BY FACTORS INTRODUCED TO COMPENSATE FOR THE REVENUE PER TRIP, LOAD FACTOR, AIRCRAFT TYPE, ETC. (THE SUGGESTED BASE OF $3.00 PER MOVEMENT COULD BE INCREASED IF CONSIDERED ADVISABLE, SINCE THE COSTS DURING MAXIMUM FOG YEARS WOULD BE HIGHER AND SCHEDULE CHANGES FROM AFTERNOON TO MORNING FLIGHTS WOULD INCREASE THE NECESSITY FOR OPERATION OF THE AIDS.)

# ECONOMIC JUSTIFICATION

During the past several years there has been an ever increasing realization of the fact that at present the primary bottleneck in civil aviation is the inability to maintain schedule reliability. The economic implications of this fact were recognized by the President's Air Policy Commission when they reported: "Air travel will never be mass transportation until people are reasonably certain that they can depart and arrive on schedule...Problems of cancelled flights or the using of alternate airports, however, will not be solved until safe all-weather flying has been achieved...Larger expenditures for electronic aids to air traffic control, navigation, and landing will do more than anything else foreseeable today to build the airlines toward economic self-sufficiency."

A sampling has been obtained of the direct and indirect cost to certain airlines of cancellations and diversions necessitated by closed conditions at the San Francisco International Airport. Six airlines cooperated in this study.

Alternates, provisional alternates, and holding points for these six operators include Oakland, Sacramento, Half Moon Bay, Concord, Bakersfield, Palmdale, Burbank, Los Angeles, Salt Lake City, Salinas, Stockton, San Jose, Watsonville, Vallejo, Santa Rosa, and Sunnyvale. Direct costs of diversions vary considerably depending on the alternate. Operator A, for example, lists an average cost of $458 per diversion. Operator B lists direct costs ranging from $150 to $300 per alternate landing (but not including hotel accommodations for stranded passengers); operators C, D, and E have approximately the same direct costs when hotels, alternate transportation, meals, etc., for passengers are not considered.

THE MOST SIGNIFICANT DATA OBTAINED FROM THE SCHEDULED OPERATORS INTO SAN FRANCISCO WAS IN CONNECTION WITH TOTAL LOSSES. OPERATOR D CONCLUDED HIS REPORT OF THE CANCELLATIONS AND DELAYS DUE TO CLOSED CONDITIONS AT SAN FRANCISCO OVER A SINGLE 90-DAY PERIOD DURING THE WINTER OF 1946 WITH THE COMMENT, "BASED ON THESE IRREGULAR OPERATIONS, I BELIEVE A CONSERVATIVE ESTIMATE OF OUR LOSSES SUFFERED DURING THE PERIOD LISTED ABOVE WOULD AMOUNT TO $200,000." OPERATOR A STATED, "PARAMOUNT IN IMPORTANCE AND NOT MEASURABLE IN DOLLARS IS PASSENGER GOODWILL AND PUBLIC FAITH, WHICH ARE GENERATED BY UNBROKEN REGULARITY OF OPERATIONS". ANOTHER AIRLINE, DURING ONE MONTH IN A MAXIMUM FOG YEAR, CANCELLED 162 TRIPS DUE TO WEATHER CONDITIONS AT THE SAN FRANCISCO AIRPORT. IN THE SAME MONTH THE SAME LINE DELAYED 77 TRIPS. 'PASSENGER GOODWILL AND PUBLIC FAITH' MUST HAVE BEEN SADLY SHAKEN DURING THIS PARTICULAR MONTH.

BASED UPON THE DATA MADE AVAILABLE BY THE AIRLINES OPERATING INTO SAN FRANCISCO AND UPON THE AVERAGE LOAD FACTORS DURING THE PERIODS IN QUESTION, WEATHER CANCELLATIONS AND DELAYS ARE COSTING THE OPERATORS APPROXIMATELY $22.60 PER PASSENGER. THIS FIGURE, OF COURSE, TOTALLY DISREGARDS BY FAR THE MOST IMPORTANT LOSS TO THE AIRLINES, THE POTENTIAL PASSENGER AND CARGO VOLUME WHICH WILL BE WITHHELD UNTIL SUCH TIME AS THE AIRLINES CAN OFFER SCHEDULE RELIABILITY EQUAL TO THAT OF THE SURFACE CARRIERS. HOWEVER, THE ECONOMIC JUSTIFICATION OF AN ALL-WEATHER OPERATION INTO SAN FRANCISCO DOES NOT REQUIRE THE INCLUSION OF POTENTIAL REVENUE IF IT CAN BE SHOWN THAT PRESENT OUT-OF-POCKET COSTS TO THE AIRLINES EXCEED THOSE OF THE PROPOSED INSTALLATIONS. LET US ASSUME, CONSERVATIVELY, THAT THE AVAILABILITY OF AN INTEGRATED SYSTEM OF LANDING AIDS WOULD ELIMINATE AN AVERAGE AIRLINE LOSS OF $20.00 PER PASSENGER DIVERTED OR NOT CARRIED FROM SAN FRANCISCO DURING PERIODS OF UNFAVORABLE WEATHER.

With the figure of $20 per passenger in mind, let us consider the probable number of flights which will be subject to a fog risk at the San Francisco International Airport. The following table indicates the number of flights which might be subjected to diversion:

Annual Totals of Schedules
Interrupted by Low Visibility

0000 - 1200

| Minimum Condition | Arrivals Avg | Arrivals Max | Departures Avg | Departures Max | Totals Avg | Totals Max |
|---|---|---|---|---|---|---|
| 200' & 1/2 mi. | 102 | 457 | 124 | 558 | 226 | 1015 |
| 300' & 3/4 mi. | 133 | 600 | 161 | 750 | 294 | 1350 |
| 400' & one mi. | 182 | 795 | 221 | 967 | 409 | 1762 |

1200 - 2400

| | | | | | | |
|---|---|---|---|---|---|---|
| 200' & 1/2 mi. | 12 | 60 | 11 | 55 | 23 | 115 |
| 300' & 3/4 mi. | 20 | 80 | 18 | 73 | 38 | 153 |
| 400' & one mi. | 23 | 100 | 21 | 92 | 44 | 192 |

Yearly Totals

| | | | | | | |
|---|---|---|---|---|---|---|
| 200' & 1/2 mi. | 114 | 517 | 135 | 613 | 249 | 1130 |
| 300' & 3/4 mi. | 153 | 680 | 179 | 823 | 332 | 1503 |
| 400' & one mi. | 205 | 895 | 242 | 1059 | 447 | 1954 |

Without landing aids we can expect at least 447 San Francisco operations to be interrupted by weather in 1950. By utilizing the estimated annual landing aids operating and amortization costs developed in Section 4 it can be calculated that the average cost per passenger per landing aids operation in 1950 would be approximately

$15.00 AS COMPARED WITH THE AVERAGE COST OF $20.00 PER PASSENGER WHICH THE AIRLINES ARE NOW FORCED TO PAY WHEN FLIGHTS ARE DIVERTED OR CANCELLED. THUS IT APPEARS THAT THE ACTUAL COST TO THE AIRLINES FOR THE OPERATION AND AMORTIZATION OF THE LANDING AIDS NECESSARY FOR AN ALL WEATHER OPERATION WOULD BE SOMEWHAT LESS THAN THE COST OF HANDLING THE DIVERSIONS AND THE CANCELLATIONS NECESSITATED BY THE LACK OF ALL WEATHER FACILITIES.

IF LANDING AIDS ARE NOT AVAILABLE IN 1950 IT IS POSSIBLE THAT AS HIGH AS 50,000 HOURS OF SAN FRANCISCO PASSENGERS' TIME MAY BE WASTED WHEN SCHEDULES ARE INTERRUPTED BY WEATHER. THE PUBLIC EXPECTS AND IS ENTITLED TO THE BEST SERVICE THE AIRLINES CAN RENDER WITHIN CERTAIN ECONOMIC LIMITATIONS. OBVIOUSLY, IF THE SCHEDULED CARRIERS ARE ABLE TO OFFER ADDED SAFETY AND RELIABILITY THEY WILL HAVE ELIMINATED A MAJOR CAUSE OF THE PRESENT LACK OF PUBLIC CONFIDENCE IN THE AIRLINES. TO BE ABLE TO DO THIS WITHOUT AN INCREASE IN OPERATING COSTS WOULD BE AN ATTRACTIVE SOLUTION TO AN EXTREMELY CRITICAL PROBLEM. RELIABLE SCHEDULES WILL ENCOURAGE AIR TRANSPORTATION TO AND FROM THE BAY AREA, WHICH IN TURN WILL BUILD UP THE AIRPORT REVENUES.

IN ADDITION TO THE SPECIFIC FIGURES PRESENTED HERE IN CONNECTION WITH THE ECONOMIC JUSTIFICATION OF LANDING AIDS, WE WOULD LIKE TO PRESENT A GENERAL APPROACH TO THE PROBLEM WHICH WE FEEL MERITS CONSIDERATION.

THE EFFECTIVENESS OF THE INTEGRATED SYSTEM OF LANDING AIDS LIES IN THE FACT THAT EVEN ZERO/ZERO CONDITIONS ARE MADE FLYABLE BY THE THREE BASIC COMPONENTS--ELECTRONIC AIDS, HIGH INTENSITY LIGHTING, AND FOG DISPERSAL. THE USE OF AN INTEGRATED SYSTEM THUS PRESENTS THE ONLY MEANS NOW AVAILABLE BY WHICH THE MINIMUMS MAY BE OFFICIALLY MODIFIED SO THAT THE PROBABILITY OF COMPLETING A SCHEDULED FLIGHT CAN BE COMPARABLE WITH THE PROBABILITY OF COMPLETING A SCHEDULED JOURNEY BY SURFACE TRANSPORTATION.

Unfortunately, there has been a persistent belief that the complete Integrated Landing System is "too costly to be utilized on a widespread scale". Under the most extraordinary conditions the investment for equipping a major airport with a complete system will never run more than 5 per cent of the cost of the airport. Without an expenditure for landing aids, the airport becomes worthless when the weather is adverse. The railroads would consider it unthinkable to tie up the whole of a very expensive network of trackage just because an automatic signalling system was "too costly to be utilized on a widespread scale".

Landing aids costs are almost always quoted on a "cost per landing" basis. Obviously when only one airport is under consideration, this is the only method available. However, so far as commercial airline operations are concerned, all costs, in the long run, must be reduced to the cost per passenger or ton mile for all operations whether in fair or foul weather.

For purposes of illustration, suppose that an airline had (1) an average operating expense of $.5093 per ton mile; (2) an average haul of 750 miles; (3) an average pay load per landing of 3 tons; and (4) that the complete integrated landing system would be used for one landing in 50 at a cost of $500 per landing (the San Francisco figure is approximately 1 in 100). Then the overall average landing aids costs for all flights are 500 ÷ (3 x 750 x 50) dollars per ton mile, or $.0044 per ton mile. In this hypothetical case, the cost of the landing aids necessary to enable the airlines to establish a service equal to that of surface transportation will increase operating costs from $.5093 per ton mile to $.5137 per ton mile.

In order to safely achieve true all-weather operation and 100 per cent schedule reliability at San Francisco all the basic aids which have been recommended herein must be installed, including FIDO. This Integrated Landing Aids System is a team, in which each

COMPONENT PLAYS AN ESSENTIAL PART, AND IN WHICH THE MULTIPLICITY OF FURNISHED INFORMATION CONTINUALLY CROSS-CHECKS THE OPERATION OF EACH COMPONENT AND THE PILOT'S USE OF IT. FAILURE TO INCLUDE THEM ALL MEANS A LESSENING OF THE SAFETY OF EACH INSTRUMENT OPERATION, AND AN INCREASED LIKELIHOOD OF CANCELLATIONS AND DELAYS.

THE SYSTEM, MOREOVER, MUST BE BACKED UP BY CAREFUL TRAINING OF THE PILOTS WHO USE IT AND THE GROUND PERSONNEL WHO OPERATE AND MAINTAIN IT. SINCE THE VALUE OF THE AIDS WILL BE PROPORTIONATE TO THE SKILL OF THE MEN MAKING USE OF THEM, CONTINUED PRACTICE WILL BE NECESSARY TO MAINTAIN PROFICIENCY.

IN SUMMARIZING THE ECONOMIC JUSTIFICATION FOR THE INSTALLATION OF LANDING AIDS IT MAY BE POINTED OUT THAT THE COST OF DIVERSIONS AND CANCELLATIONS TO ONE AIRLINE DURING A 90 DAY PERIOD IN 1946-47 WAS $20,000.00 MORE THAN THE ESTIMATED ANNUAL AMORTIZATION AND OPERATING COSTS OF AN INSTALLATION WHICH WOULD ELIMINATE THE NECESSITY FOR INTERRUPTED SCHEDULES AT THE SAN FRANCISCO INTERNATIONAL AIRPORT.

WHEN SAN FRANCISCO IS ABLE TO GUARANTEE AN ALL WEATHER OPERATION, IT IS HOPED THAT A METHOD OF DISTRIBUTING THE LANDING AIDS COST CAN BE WORKED OUT WHICH WILL PERMIT THE CARRIERS TO SHARE THE COST IN THE SAME PROPORTION AS THEY SHARE THE MARKET FOR AIR TRANSPORTATION TO AND FROM SAN FRANCISCO.

# RECOMMENDATIONS

SECTION 6.

## Instrument Landing System

The glidepath transmitter should not be moved from its present site until Runway 28L is completed. It should then be placed approximately 300 feet north of 28L runway edge, and not less than 750 feet from 28L runway threshold. The site chosen should be on the east side of Runway 19L. The new site should not be permanently fixed until flight checks have demonstrated that it does not introduce "dips" in the electronic glidepath. The flatness of the airport terrain makes such irregularities unlikely.

Selection of the localizer transmitter site is a more difficult problem. During the two years of airport construction work remaining, the localizer transmitter, in its present location off the northwest end of Runway 28R, will probably be influenced by the presence of trucks and construction equipment to an extent sufficient to produce shifting of the beam pattern from its proper orientation down the runway centerline. Since distance from the transmitter is only one of several factors involved in producing such a shift, it cannot be categorically stated that inside a certain radius trucks and planes will cause a shift, and that outside it they will not. However, it should be possible to avoid all or most of such difficulties by a careful choice of transmitter site. Experience demonstrates that the wisest choice is to obtain maximum separation between the localizer transmitter and buildings, hangars, parked aircraft, and vehicles or aircraft crossing the localizer course in front of the transmitter.

It may become necessary to abandon the present localizer site before Runway 28L comes into use as the building program advances and construction activity becomes concentrated in this area. Should abandonment become necessary, a temporary site approximately 3000 feet from the northwest end of Runway 28R is suggested for use during the construction period and until the present localizer (or its CAA replacement) is permanently installed to serve Runway 28L. In the interim, use might conveniently be made of the military-type localizer (AN/CRN-10) at the suggested temporary site. The portable military localizer is entirely satisfactory for general use and would save moving expense. This equipment can be placed in operation in a few hours.

The permanent site for the localizer off the northwest end of 28L must be carefully chosen to minimize course shifts which may be caused by modification of the old terminal building and by planes taxiing to and from the United Air Lines maintenance area. A site as close to the end of 28L as the present site is to 28R would place the localizer undesirably close to the old terminal building; moreover, surface vehicles and aircraft would cross the course immediately in front of the transmitter with the almost certain result of causing shifts in the course. It would be preferable to choose a site 3000-3500 feet from the northwest end of 28L, on the extended centerline. The undesirable influences mentioned above will be minimized by this site, and perhaps eliminated altogether. In this connection, it should be remembered that in low visibility conditions tower operators may be unable to see vehicles and equipment moving in this area.

There may be serious objections to the permanent site suggested. If so, before any final decision is taken, it is strongly advised that all proposed sites be investigated by installing the AN/CRN-10 localizer on each site and making flight checks of the course,

WHILE SUBJECTING THE TRANSMITTER TO ALL THE POSSIBLE CONCENTRATIONS AND COMBINATIONS OF INTERFERENCE PRODUCED BY VEHICLES AND AIRCRAFT. THE ASSURANCE OF STABILITY THUS GAINED WILL BE WORTH THE ADDITIONAL TIME AND TROUBLE.

IT HAS BECOME MORE OR LESS STANDARD TO SUPPLY TWO 75 MEGACYCLE MARKER BEACON TRANSMITTERS WITH ILS, RATHER THAN THE THREE USED BY THE MILITARY SERVICES. THESE ARE LOCATED APPROXIMATELY 4 1/2 MILES (OUTER MARKER) AND 3500 FEET (MIDDLE MARKER) FROM THE RUNWAY THRESHOLD. THE THIRD OR BOUNDARY MARKER BEACON, LOCATED 200 - 250 FEET FROM THRESHOLD, IS OFTEN OMITTED. HOWEVER, WE BELIEVE THAT THE BOUNDARY MARKER SHOULD BE INCLUDED. AS CEILING AND VISIBILITY MINIMUMS ARE REDUCED, IT BECOMES VERY IMPORTANT TO PROVIDE THE PILOT WITH EVERY POSSIBLE AID IN DETERMINING HIS EXACT POSITION, ESPECIALLY NEAR THE TOUCHDOWN POINT. THE BOUNDARY MARKER SERVES AS AN INDEPENDENT CHECK AT THIS CRITICAL POINT ON THE PILOT'S UNDERSTANDING OF THE VISUAL AID PROVIDED BY APPROACH AND RUNWAY LIGHTS. WE CONSIDER THAT OVERLAPPING ELECTRONIC AND VISUAL AIDS ARE HIGHLY DESIRABLE.

WHEN RUNWAY 28L IS PLACED IN SERVICE, IT WILL BE NECESSARY TO RELOCATE THE MIDDLE MARKER AT A POINT 3500 FEET OUT ON THE EXTENDED CENTERLINE OF THIS RUNWAY. THE OUTER MARKER NEED NOT BE SHIFTED, SINCE THE CHANGE IN DISTANCE IS NEGLIGIBLE AND ITS VERTICAL BEAM PATTERN WILL SERVE THE NEW COURSE ADEQUATELY FROM THE PRESENT SITE. IF A BOUNDARY MARKER IS USED, IT SHOULD BE INSTALLED ON THE EXTENDED CENTERLINE OF 28L, MIDWAY BETWEEN THE THRESHOLD AND THE TAXIWAY TO 28R.

MONITORING EQUIPMENT FOR THE ILS LOCALIZER AND GLIDEPATH, AND THE CONTROLS FOR ALL ILS COMPONENTS, SHOULD BE INSTALLED IN THE TOWER TO ASSURE OPERATORS OF PROPER INSTRUMENT PERFORMANCE AT ALL TIMES.

## Compass Locator Stations

Omni-directional radio beacons (Type H) are very useful additions to the electronic aids provided for pilot guidance. It is suggested that four compass locators of low power be installed for immediate use. They will be helpful to planes not equipped with ILS and for pilots not trained in using it; also, they will provide an independent check for the pilot on the accuracy of the ILS localizer course and assist in following it; they will provide absolute identification of the airport bearing in the immediate vicinity; and will constitute a satisfactory low approach aid for planes landing on the cross runway, 19R.

Two transmitters should be used on Runway 28R, the first located on the extended centerline at the edge of the fill southeast of the threshold, the second on the extended centerline 2000-2500 feet from the northwestern end of 28R. After completion of 28L, these transmitters should be removed to the same relative positions on the extended 28L centerline.

A second pair of compass locator transmitters will be particularly useful on Runway 19R when it is placed in service. The distances from the runway end should be equivalent to those on 28R described above. Runway 19R, which will not be served by ILS, will be used predominantly in rain and in moderate visibility and ceiling conditions. Since its approach is over the bay, a simple procedure can be established for letting down through overcast using the compass locators to establish the centerline and the altimeter and rate of descent indicator for a glidepath. Such a procedure is safe down to 200 feet over water, and will result in the plane dropping out of the overcast lined up with the runway. The pilot can then pick up the "stub" approach light system recommended for this approach, and the runway lights, to make an easy touchdown.

The antennas for these stations should be of the balanced "T" capacity-loaded vertical type, 10-15 feet in height. To obtain capacity loading, it will be necessary to stretch a wire perpendicular to the extended centerline between two telephone poles equally spaced off the centerline. The vertical antenna is connected in the center of this supporting wire. Although this is not an efficient antenna for general radio use, it is entirely satisfactory for this purpose.

For simplicity in tuning automatic direction finders in the cockpit, these radio beacons should have frequencies about 10 kc apart. The pilot can then change from the first ground station to the second without delay. With dual ADF, the pilot merely tunes both stations in, then follows the course which aligns the two indicators together.

The four stations should be coded by letter and by number (i.e. NX-1, NX-2, NX-3, NX-4). NX-1 and 2 would be located on 28R (later 28L) and NX-3 and 4 would be on 19R. Control circuits should emanate from the tower, and there should be separate circuits for 28L and 19R. Only the stations serving the runway in use would be operated at any one time, and the same pair of frequencies can then be used on each runway. These stations should have a relatively low power output, on the order of 10 to 50 watts, depending on the radius over which coverage is desired.

## VHF Direction Finder

The Very High Frequency Direction Finder recommended for San Francisco is a small unit such as Model D.B.F. This unit can easily be installed in the tower for ready

access. The set uses a compact Adock-type antenna. For the greatest accuracy this antenna must be located above any surrounding objects which cause reflections and might thereby affect the indication given by the instrument. The antenna is a small unit requiring only a light support. The antenna lead-in cable supplied with the set also transmits the power for the motor in the antenna base which operates the goniometer. The power requirement is approximately 250 watts.

## Search Radar

The search and height finder radar indicator should be located in the tower until such time as it may be appropriate to install the precision radar approach system. This is advisable because these radars will at first be used not only for traffic control, but also to monitor the final approach of an aircraft using the Instrument Landing System or making an A.D.F./altimeter approach through the overcast.

Space in the administration building should be allocated for eventual use for the search and height finding radars as traffic control devices. The respective antennas and their radar transmitter-receivers should be located atop the administration building and separated from each other sufficiently so that neither antenna can blank out the area to be scanned by the other. Care must be exercised that the distance from the receivers to the indicators shall not be so great as to require additional video amplifiers, and also in order that the synchronizing circuits and other controls will not be excessive in length. Reducing the distance between the various electronic devices to a minimum cuts maintenance time on the equipment.

## Ground Control Approach

It is suggested that any present preparation for a future GCA installation be limited to the provision of three 4-inch conduits for the AC power supply and the coaxial cables carrying the video signal from the field installation to the tower indicators and for synchronizing circuits. The latter conduit should have bend radii of not less than 36 inches. The conduit runs should be laid in a direct line from the tower radar control center to the field installation in order to have as few bends in the cabling as possible. The site recommended at this time will undoubtedly be the most propitious regardless of which form the GCA precision equipment takes. Analysis of the meteorological data does not indicate the necessity for providing more than one runway with electronic aids whose function is to guide aircraft through a very low ceiling and visibility condition.

## Radar Beacons

We recommend that four radar beacons be considered for installation after completion of the expansion program. By that time airborne search radar should be in common use, and it will be desirable to make this radar serve as a part of the electronic navigation system.

These beacons should be located off the ends of Runways 28L and 19R on the extended centerline in the housings provided for the compass locators.

The beacons should operate in the X band (3 centimeters) and, like the compass locators, should be coded to indicate their locations. The circuits should be controlled in the tower, permitting separate activation of the pair serving the landing runway. They should be

OF THE "TRIGGERED" TYPE WHICH TRANSMITS ONLY WHEN THE RECEIPT OF IMPULSES FROM AIRBORNE SEARCH RADAR INDICATES THE PRESENCE OF AN AIRCRAFT SEEKING NAVIGATIONAL AID. IT IS SUGGESTED THAT ANY OTHER GROUND RADAR EQUIPMENT WHOSE SCAN INCLUDES THESE BEACONS BE INTERLOCKED WITH THEM, SO THAT IMPULSES FROM THE OTHER GROUND RADAR WILL NOT CAUSE CONTINUOUS AND WASTEFUL BEACON OPERATION; HOWEVER, THIS IS NOT ESSENTIAL TO THEIR SUCCESSFUL OPERATION.

Power Requirements

| | Kilowatts |
|---|---|
| Compass Locators | 2 - 3 |
| ILS Localizer | 5.0 |
| ILS Glidepath | 1.5 |
| 75 M.C. Marker Beacons | 0.5 - 1.0 |
| V. H. F. Direction Finder | 0.25 |
| Search Radar | 5.0 |
| Height Finding Radar | 5.0 |
| Radar Beacons | 1.5 |
| Ground Control Approach | |
| (a) Military version | 10.0 |
| (b) Commercial version | 7 1/2 |

## Approach Lights

It has been demonstrated that incandescent "high intensity" approach lights of the proper design will provide adequate guidance for landings in weather conditions as low as 1/4 mile daylight object visibility and 75-foot ceiling. Pilots using the lights in these conditions must, of course, be thoroughly trained to interpret the guidance correctly and instantaneously, and must also use electronic aids with great accuracy.

A complete approach lighting system should be installed on the instrument Runway 28L, in accordance with the recommended ANC standard. The system should be 3000 feet long and the rows 250 feet apart, the maximum allowable separation. Lights should be spaced 100 feet apart along the outermost 1000 feet, and 200 feet apart from 2000 feet out to the runway.

The lights should be as near runway elevation as terrain will permit between the threshold and the shoreline. The remaining lights, over the bay, may be mounted on piling. It is suggested that these lights be raised to an elevation of 10 feet above runway level, beginning immediately at the shoreline, in order to minimize the amount of salt spray to which they will be subjected. Corrosion by salt spray will be a problem requiring attention; consultation in advance with the manufacturer of the units purchased may serve to forestall much trouble from this source.

The approach lights used in the recommended configuration must be visible throughout a vertical plane of considerable size at the middle marker, and throughout similar vertical planes between the middle marker and the runway. This coverage is made necessary by the range of deviations to be expected above or below and to the left or right of

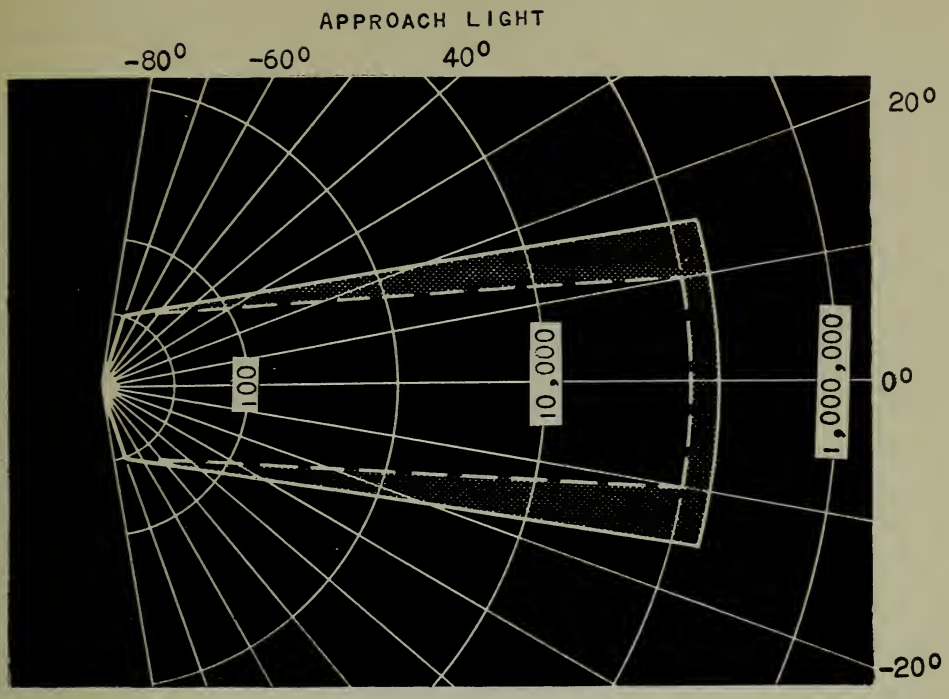



FIGURE 24
VERTICAL CANDLEPOWER DISTRIBUTION
(CLEAR LIGHT) AT 0° IN HORIZONTAL PLANE

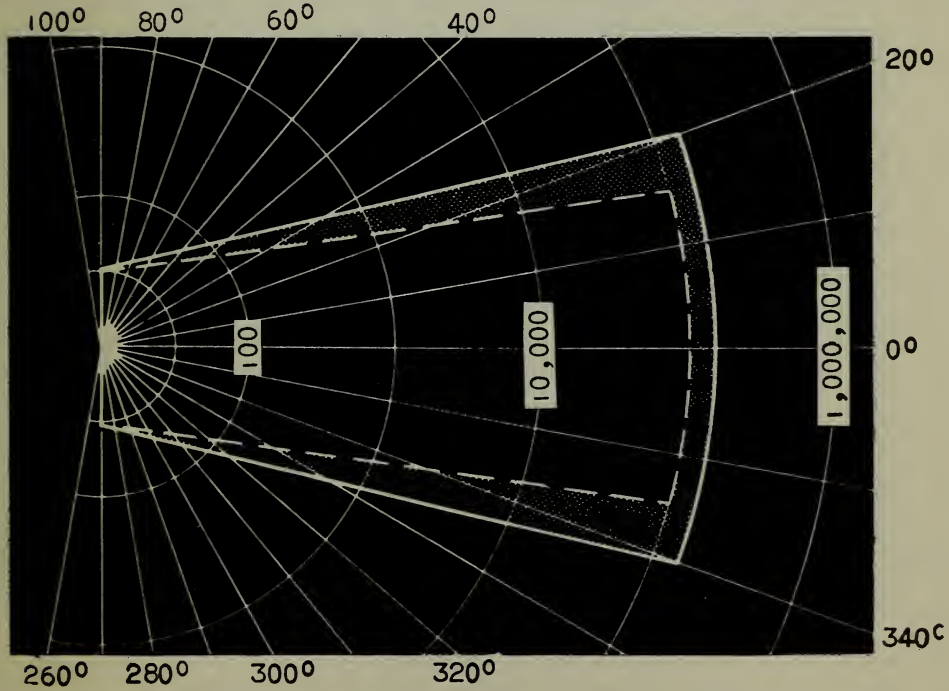



FIGURE 25
HORIZONTAL CANDLEPOWER DISTRIBUTION
(CLEAR LIGHT) AT 0° IN VERTICAL PLANE

THE "IDEAL" GLIDEPATH MARKED OUT BY ILS. THE EXPECTED "PORTAL" AT THE MIDDLE MARKER IS OF THE ORDER OF 500 FEET WIDE AND FROM 100 FEET BELOW TO 200 FEET ABOVE THE "IDEAL" GLIDEPATH AT THIS POINT. IT IS RECOMMENDED THAT INCANDESCENT UNITS PRODUCING A UNIFORM RECTANGULAR CANDLEPOWER DISTRIBUTION BE USED AS THE APPROACH LIGHT SOURCE. THE UNITS SHOULD HAVE A BEAM DIVERGENCE OF 30 - 40 DEGREES IN THE HORIZONTAL PLANE AND 20 - 30 DEGREES IN THE VERTICAL. WITH COLOR FILTERS IN PLACE, THE UNITS SHOULD PRODUCE NOT LESS THAN 25,000 PEAK CANDLEPOWER, AND THE DISTRIBUTION SHOULD BE SUCH THAT THE CENTRAL SOLID ANGLE OF APPROXIMATELY 15 BY 10 DEGREES IS NOT LESS THAN 15,000 CANDLEPOWER. ADDITIONAL COVERAGE AND CANDLEPOWER IS HIGHLY DESIRABLE IF IT CAN BE OBTAINED WITHOUT EXCESSIVE EXPENSE IN RUGGED, EASILY MAINTAINED LIGHTING UNITS. FIGS. 24 AND 25 SHOW AN IDEALIZED CANDLEPOWER DISTRIBUTION RECOMMENDED FOR THE APPROACH LIGHTS. THE UNIT CHOSEN SHOULD HAVE NOT LESS THAN THE MINIMUM COVERAGE SHOWN IN THE CENTRAL SECTION. THE OPTIMUM OUTER DISTRIBUTION IS SUGGESTED IF OBTAINABLE.

THE APPROACH LIGHT UNIT SHOULD BE ONE WHICH WILL REQUIRE A MINIMUM OF SERVICE AND ATTENTION. INSTALLATION AND ALIGNMENT, BECAUSE OF ITS WIDE BEAM, WILL BE RELATIVELY SIMPLE AND SHOULD NOT REQUIRE READJUSTMENT AFTER ITS INITIAL SETTING. THE SYSTEM SHOULD BE SUCH THAT AN INSPECTION AND CLEANING, APPROXIMATELY 3 TIMES YEARLY, WILL MAINTAIN THE UNITS IN FIRST CLASS CONDITION.

INSTALLATION OF A "STUB" APPROACH LIGHT SYSTEM ON RUNWAY 19R IS RECOMMENDED FOR THOSE MARGINAL VISIBILITY CONDITIONS IN WHICH THIS RUNWAY IS USED, USUALLY IN RAINS. THE "STUB" SYSTEM SHOULD BE ONLY 1000 FEET LONG, BUT SHOULD IN OTHER RESPECTS BE IDENTICAL WITH THE SYSTEM USED ON 28L, WITH THE LIGHTS SPACED 200 FEET APART IN EACH ROW. SUCH A SYSTEM, USED IN CONJUNCTION WITH THE RADIO COMPASS LOCATOR RECOMMENDED ELSEWHERE, WILL CONSTITUTE A SOUND APPROACH CONTROL METHOD FOR THE MARGINAL WEATHER CONDITION WHEN THIS RUNWAY COMES INTO SERVICE.

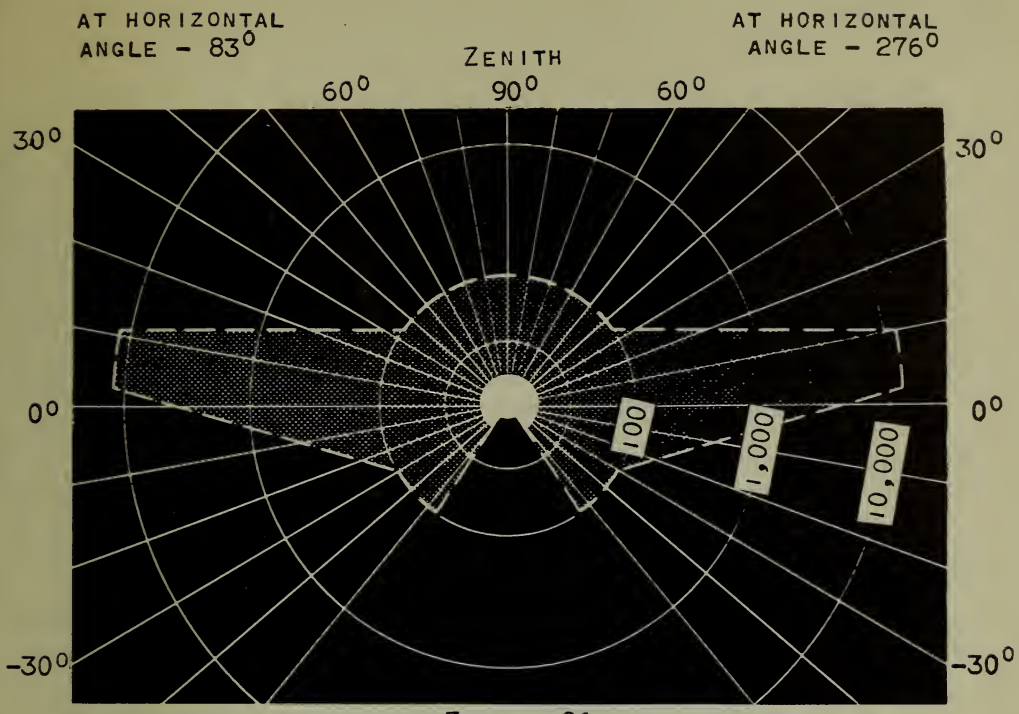



FIGURE 26

VERTICAL CANDLEPOWER DISTRIBUTION
RUNWAY LIGHTS CLEAR LIGHT

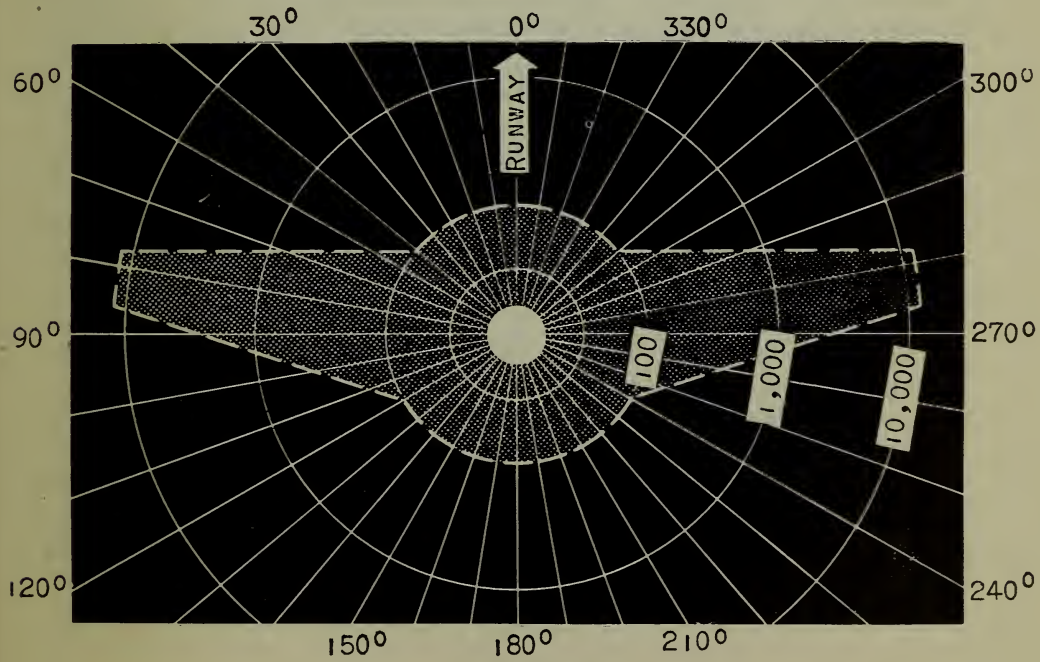



FIGURE 27

HORIZONTAL CANDLEPOWER DISTRIBUTION
RUNWAY LIGHTS CLEAR LIGHT

Installation of a "stub" approach light system immediately on Runway 28R for use until 28L is complete would materially improve the visual guidance available to pilots. It would also provide pilots landing at San Francisco an opportunity to begin their training for future landings in minimum weather.

## Runway Lights

It is recommended that a single type of high intensity runway light be installed on all runways now in use as well as those yet to be completed. Savings through quantity buying, reduced replacement stock, and the easier maintenance of the units should offset any increased cost and will give San Francisco Airport that increased margin of safety which is essential in all aircraft operations.

Spacing of the lights should be substantially uniform on all runways. Two-hundred-foot spacing is recommended on all parts of the runway except the touchdown section. With this spacing, and the candlepower distribution recommended below, the pilot should have 4 - 5 lights continuously in view ahead during landing and takeoff in 1/8 mile daylight object visibility conditions, and, of course, substantially more in conditions at or above 1/4 mile. The lights should be set as near the runway as CAA regulations permit, both to increase the effective coverage and to keep pilots on the runway.

The touchdown section of the runway, comprising the first 1500 feet inside the threshold, should have lights spaced 100 feet apart. This is the critical section from the pilot's viewpoint and should be distinctively marked off from the remainder in order that the pilot will always recognize the safe landing area. Reduction of the spacing also provides additional longitudinal coverage, and marks out a more absolute line of reference.

THE ANC STANDARD COLOR SEQUENCE SHOULD BE FOLLOWED; WITH GREEN LIGHTS MARKING THE THRESHOLD, CLEAR LIGHTS ALONG THE SAFE LANDING SECTION, AND AMBER CAUTION LIGHTS ALONG THE LAST 1500 FEET OF THE RUNWAY. PROVISION, HOWEVER, SHOULD BE MADE FOR LATER MODIFICATION. STUDIES NOW IN PROGRESS ON THE MOST DESIRABLE CODING MAY RESULT IN FUTURE CHANGES.

RUNWAY MARKER UNITS PROVIDING A RELATIVELY WIDE BEAM SPREAD ARE RECOMMENDED AS THE MOST DESIRABLE FOR LANDINGS IN LOW VISIBILITY. AT 1200 - 1400 FEET FROM THE LIGHT, THE PRINCIPAL BEAM SHOULD COVER 2/3 OR MORE OF THE RUNWAY WIDTH WITH A BEAM OF NOT LESS THAN 20,000 CANDLEPOWER. RELATIVELY UNIFORM DISTRIBUTION OF FLUX OVER AN ANGLE SUFFICIENT TO PROVIDE THE ABOVE COVERAGE (AND EQUAL COVERAGE IN THE VERTICAL DIMENSION) IS PREFERRED OVER THE CONCENTRATION OF FLUX IN A NARROW BEAM OF PROPORTIONATELY HIGHER INTENSITY. THE PLANE LOCATION IS VARIABLE WITHIN, AS WELL AS BETWEEN, APPROACHES; AND ONLY THE WIDER DISTRIBUTION WILL MAKE CERTAIN THAT GUIDANCE IS AVAILABLE TO THE PILOT AT ALL THE POSSIBLE APPROACH AND LANDING POSITIONS. IN ADDITION, THE UNITS CHOSEN SHOULD PROVIDE A LOW CANDLEPOWER LIGHT VISIBLE THROUGH 360° FOR AIRCRAFT CIRCLING THE FIELD IN CLEAR WEATHER. BI-DIRECTIONAL UNITS ARE THE MOST ECONOMICAL TO PURCHASE, AND NO DIFFERENCE HAS BEEN OBSERVED BETWEEN THE PERFORMANCE OF SUCH UNITS, WHEN PROPERLY DESIGNED, AND THOSE PROJECTING ONLY ONE MAIN BEAM. IN THE PEAK OF THE MAIN BEAMS THE CANDLEPOWER SHOULD BE NOT LESS THAN ABOUT 50,000; AND IF GREATER CANDLEPOWER CAN BE OBTAINED FOR DAYLIGHT USE UNDER LOW VISIBILITY CONDITIONS, IT IS MUCH TO BE DESIRED.

FOR MOST EFFECTIVE AND ECONOMICAL SERVICE OVER THE YEARS, RUNWAY LIGHTS SHOULD BE OF A SIMPLE RUGGED DESIGN. THEY SHOULD NOT EXCEED 24 INCHES IN HEIGHT ABOVE THE RUNWAY, TO PREVENT PROPELLOR DAMAGE. ALIGNMENT AND LEVELLING OF THE UNITS SHOULD BE A SIMPLE PROCEDURE IN ORDER TO KEEP MAINTENANCE COSTS DOWN AND OPERATING EFFECTIVENESS UP.

## Taxiway Lights

The effectiveness of an integrated system of landing aids can be considerably reduced, so far as expeditious traffic control is concerned, if landing planes are not immediately cleared off the runway. Likewise, to maintain schedules, departing planes must get to their takeoff positions without delay. Taxiway lights, therefore, are an important part of the system as a whole.

In order to taxi quickly and surely to and from the runway in fog, the pilot needs guidance equivalent to that provided by the runway lights. The blue filters used in taxiway lights transmit only 5 to 15 per cent of the incident flux, and the effective candlepower is small unless the initial output is high. For this reason it may be desirable that San Francisco use runway markers with blue filters on the taxiway serving 10L and paralleling the ramp, the feeders from this taxiway to the ramp, and the taxiway serving 28R. It is probable that any increase in first cost of these units over conventional types will, on the more strategic runways, be offset by savings resulting from the simplification and standardization of maintenance procedures.

The remainder of the taxiways can be served adequately by the use of conventional taxiway lights. As an added safety measure, it is suggested that signals be used at a few points, as noted on the plan, to control planes crossing the active runways.

## Maintenance

Airport lighting equipment used for landings in bad weather must be kept in first-class condition at all times. The primary electronic devices, whose maintenance requirements are even more critical, are the responsibility of CAA, but the approach and runway lights will in all probability be maintained by the airport's local administration.

Excessive maintenance demands could easily become an impossible burden upon the administration of an airport. Therefore, dependability and simplicity of construction have been second only to operating performance as a basis for determining general lighting requirements. Thought must be given to standardization of units and of parts, and to the ease of procurement of various items. If the recommendations made herein are closely followed, they should result in a system which will provide maximum usage of the San Francisco Airport at a minimum rate of maintenance expenditure.

## Wind Tetrahedrons (tower controlled)

These visual aids are not directly a part of the landing aids with which this report is concerned. Nevertheless, they are of great importance in weather conditions above the minimum, and information provided by them should be readily accessible to pilots from any direction in the airport vicinity. It is recommended that at least two and possibly three should be as close to the runway ends as is possible without hazard to aircraft, or subjecting them to prop wash. These locations should, of course, be free of false local currents produced by adjacent buildings or other obstructions.

## Controls and Circuits

### Lighting Vault

All line voltage transformers, regulators, relays, oil switches, etc., for all the lighting systems should be centrally located in a vault placed either in the administration building or wherever is most convenient. This vault should provide space for possible future modifications and new installations, since the final pattern of visual aids has by no means been set. It should include an alternate control station for all the systems,

BOTH AS AN EMERGENCY CONTROL POSITION IN CASE OF MALFUNCTIONING TOWER EQUIPMENT, AND AS AN AID IN MAINTENANCE WORK. TWO-WAY COMMUNICATION WITH THE TOWER IS ESSENTIAL AT THE VAULT.

### Brightness Control

THE STANDARD INTENSITY CONTROLS SUPPLIED BY MANUFACTURERS OF AIRPORT LIGHTING EQUIPMENT MAKE PROVISION FOR FIVE BRIGHTNESS SETTINGS FROM 100 PER CENT DOWN TO 1 PER CENT. EXPERIENCE OVER THE YEARS INDICATES THAT ALL OF THESE SETTINGS ARE DESIRABLE TO COVER VARIOUS CONDITIONS OF WEATHER, PILOT PREFERENCES, AND AIRCRAFT COCKPIT CUTOFF; USE OF STANDARD REGULATORS IS THEREFORE RECOMMENDED. MODIFICATIONS WOULD ONLY ADD UNNECESSARY EXPENSE.

STUDIES ARE IN PROGRESS AT THE PRESENT TIME OF MEANS FOR PROVIDING AUTOMATIC INTENSITY CONTROL OF APPROACH AND RUNWAY LIGHTING SYSTEMS BASED UPON AUTOMATIC CONTINUOUS DETERMINATION OF LIGHT CONDITIONS AND ATMOSPHERIC TRANSMISSIVITY WITH SUITABLE MEASURING DEVICES. SUCH CONTROLS WILL RELIEVE TOWER OPERATORS OF AN ADDITIONAL RESPONSIBILITY AND WILL MAKE CERTAIN THAT THE PROPER INTENSITY--NEITHER TOO MUCH NOR TOO LITTLE--IS ALWAYS PROVIDED FOR THE PILOT. INSTALLATION OF SUCH DEVICES SHOULD BE MADE AS SOON AS THEY BECOME AVAILABLE.

### Regulators

THE MOST READILY AVAILABLE REGULATOR FOR THE APPROACH LIGHTS IS A STEP CONTROLLER. IT IS RECOMMENDED THAT THIS TYPE OF REGULATOR BE USED IN CONFORMITY WITH THE POLICY OF STANDARDIZATION.

SINCE DUAL RUNWAYS WILL BE USED, SOME DUPLICATION OF VOLTAGE AND CURRENT REGULATORS WILL BE NECESSARY. THE ADDITIONAL EXPENSE IS JUSTIFIED BY THE DECREASE IN LANDING AND TAKEOFF INTERVALS. THE STATIC TYPE, CONSTANT CURRENT REGULATOR IS PREFERRED OVER MOVING COIL TYPES BECAUSE THE FORMER PROVIDES AN ALMOST CONSTANT POWER FACTOR

OVER THE ENTIRE INTENSITY RANGE. REGULATORS OF 7 1/2 KW CAPACITY SHOULD BE USED, SINCE THEY ARE STANDARD ITEMS. USE OF A NUMBER OF THESE SMALL CAPACITY REGULATORS HAS THE ADDITIONAL ADVANTAGE THAT ONLY A SMALL SECTION OF THE INSTALLATION GOES OUT IN CASE OF REGULATOR FAILURE.

INTENSITY CONTROLS OF A SIMILAR TYPE WILL BE REQUIRED FOR THE HIGH INTENSITY TAXIWAY LIGHTS.

CIRCUITS

IT IS SUGGESTED THAT 3000 OR 5000 VOLT CABLE BE USED IN RUNWAY CIRCUITS, SUITABLE FOR DIRECT BURIAL, OF THE KIND EMPLOYED IN UNDERGROUND STREET LIGHTING CIRCUITS. IN CASE OF CABLE FAILURE, REPLACEMENT CABLE CAN BE QUICKLY OBTAINED FROM MUNICIPAL OR POWER COMPANY STOCK, OR FROM A LOCAL SUPPLIER. SINCE THESE AGENCIES MAINTAIN LARGE STOCKS, THE AIRPORT WILL NOT NEED TO KEEP ITS OWN. THE SAME CABLE CAN BE USED IN THE APPROACH LIGHTING SYSTEM IF THE FEEDERS ARE ARRANGED AT PROPER VOLTAGE.

RUNWAY LIGHT CIRCUITS SHOULD BE LOOPED IN SECTIONS COMPRISING THE LIGHTS ON BOTH SIDES OF THE RUNWAY SECTION. CIRCUIT FAILURE WILL THEN CUT OUT ONLY A SHORT SECTION OF THE TOTAL LENGTH, PARTICULARLY IF 7 1/2 KW REGULATORS ARE USED. IT IS EASY FOR A PILOT TO LAND ON AN INTERRUPTED RUNWAY LIGHT SYSTEM, PROVIDED THE GAPS ARE NOT GREAT; WHEREAS, A SOURCE OF DANGEROUS CONFUSION WOULD BE INTRODUCED IF HE HAD TO CHOOSE ONE OR THE OTHER SIDE OF A SINGLE LIGHT ROW AS INSTRUCTED BY THE TOWER.

INDIVIDUAL TRANSFORMERS SHOULD BE USED AT EACH APPROACH LIGHT TO REDUCE VOLTAGE DROP, AND AUTOMATIC CIRCUIT BREAKERS SHOULD BE AN INTEGRAL PART OF THE TRANSFORMERS. THESE TRANSFORMERS SHOULD BE STANDARD RATHER THAN SPECIALLY-MADE ITEMS. INDIVIDUAL ISOLATING TRANSFORMERS SHOULD BE USED AT EACH RUNWAY LIGHT TO REDUCE THE HAZARD TO MAINTENANCE PERSONNEL AND TO ELIMINATE THE POSSIBILITY OF HIGH VOLTAGE ARCING IN CASE OF COLLISION.

## Power Requirements

| | Kilowatts |
|---|---|
| **Approach Lights:** | |
| 3000-foot installation | 200 |
| 1000-foot installation | 50 |
| **Runway Lights:** | |
| 200-foot spacing; 2 KW per thousand feet | 19 |
| 100-foot spacing; 4 KW per thousand feet | 12 |
| (Totals are for two runways only, since only two will be lighted at any one time.) | |
| **Taxiway Lights:** | |
| Modified Runway Markers; 2 KW for 10 lights | 40 |
| (Spacing variable; to be used on taxiways to and from 28R and 28L only.) | |
| Regular Taxi Lights; 0.40 KW for 10 lights | 24 |
| TOTAL: | 345 |

NOTE: These requirements are for operation at 100% brightness, representing peak demand. The lights will be operated at 100% only a small fraction of the total annual time.

As previously mentioned, the lowest minimums CAA permits with present electronic aids and high intensity lights, even under the most favorable conditions of airport terrain and pilot experience, are: a ceiling of 200 feet and a visibility of 1/2 mile. According to meteorological records, fog (or low stratus) is the only obscuring agent which produces more severely restricted conditions at San Francisco Airport. Consequently, a fog dispersal system capable of producing the required minimums is a necessity if true all-weather operation is to be realized.

On the average, there are 123 hours per year when fog reduces the ceiling to less than 300 feet and/or the visibility to less than 3/4 mile; and an average of 96 hours per year when conditions are below 200 feet and 1/2 mile. It is possible, however, for conditions to be below 300 feet and 3/4 mile as much as 545 hours per year; or below 200 feet and 1/2 mile as much as 412 hours per year. Fog, on the average, lasts 4 hours; but, on rare occasions, it may persist for 24 hours or longer.

## Design Principles

The burner line locations and thermal outputs recommended for a FIDO installation at San Francisco International Airport are based upon design principles developed from wind tunnel studies of scale models made during the war at universities in the United States and England. The purpose of these studies, made in clear air, was the determination of the vertical temperature distribution produced by a continuous burner line in the atmosphere at various distances downwind. If it is assumed that the limit of the cleared region will coincide with a clear air isothermal surface defined by the air temperature rise, $\Delta T$, it is possible to calculate from the wind tunnel results, the probable height of the ceiling to be expected from a given burner line in a given wind condition.

For its FIDO designs in the United States, AFA has adopted the $\Delta T = 3^{o}F.$ isothermal surface. A $3^{o}F.$ temperature rise represents sufficient heating to vaporize the heaviest fogs likely to occur, and also to raise the air temperature enough to accommodate the added water vapor. It was shown in the Meteorological Analysis Section that the heaviest fog likely to occur was one in which the water content was 0.4 gms/$m^3$. The following table shows the increase in temperature of saturated air necessary to vaporize and accommodate the indicated additional water:

Fog Liquid Water Content

| Air Temp.$^{o}F.$ | 0.1gm/$m^3$ | 0.2gm/$m^3$ | 0.3gm/$m^3$ | 0.4gm/$m^3$ |
|---|---|---|---|---|
| $30^{o}$ | $0.7^{o}$ | $1.4^{o}$ | $2.1^{o}$ | $2.8^{o}$ |
| $40^{o}$ | $0.6^{o}$ | $1.2^{o}$ | $1.8^{o}$ | $2.4^{o}$ |
| $50^{o}$ | $0.5^{o}$ | $1.0^{o}$ | $1.5^{o}$ | $2.0^{o}$ |
| $60^{o}$ | $0.4^{o}$ | $0.8^{o}$ | $1.2^{o}$ | $1.6^{o}$ |

The lowest temperature recorded in San Francisco since 1871 was $27^{o}F.$; the lowest temperature ever recorded at the San Francisco International Airport was $30^{o}F.$ Therefore, a $3^{o}$ temperature rise is conservative, particularly since the lowest monthly average temperature to be expected with fog is $40^{o}F.$ In most fogs at San Francisco the $\Delta T = 1^{o}F.$ isotherm will more nearly represent the ceiling, the elevation of which considerably exceeds the $\Delta T = 3^{o}F.$ isotherm.

Wind Conditions at San Francisco Airport During Fog

| Condition | Wind Velocity (per cent of time) 0–4 mph | 5–9 mph | 10 mph & over |
|---|---|---|---|
| Ceiling less than 300' Visibility less than 3/4 mi. | 57% | 30% | 13% |
| Ceiling less than 200' Visibility less than 1/2 mi. | 64% | 31% | 6% |

Only 10% of the time when the wind blows 5 miles per hour or more does it blow from a direction other than parallel with Runway 28. Winds accompanying low visibility conditions rarely blow across Runway 28 at an angle greater than 30 degrees.

## Design Objectives

A FIDO installation, to be satisfactory, must be smooth, effective, economical in operation. To attain these objectives, certain factors must be kept in mind in selecting the equipment, and in engineering the installation:

(1) Instant ignition
(2) Sharp cutoff to prevent dribbling and smoking
(3) Centralized control of
    (a) Thermal output
    (b) Ignition
    (c) Fuel supply
(4) Maximum flexibility

## Design Recommendations

For economy, the San Francisco fog dispersal installation has been designed to clear the approach and runway in two minutes of operation; it should be burned only during the two minutes prior to the moment the plane crosses the runway threshold. Fuel burned at other times serves no useful purpose, since the heat released is dissipated or carried away by the wind. Additional fuel economy is achieved by progressively reducing the clearance height from a maximum in the approach zone down to 25 feet (for taxiing) at the opposite end of the runway. From the entrance into the clearance area, the visibility along the runway would be well over 3/4 of a mile, since the burners extend the full length of the landing runway.

THE WIDTH OF THE CLEARANCE WOULD, AT THE MINIMUM, BE APPROXIMATELY 850 FEET, FAR EXCEEDING THAT REQUIRED BY PILOTS USING ILS OR GCA.

## BURNER LINE LOCATION

THE PLACEMENT OF THE BURNER LINES ALONG THE RUNWAY IS DICTATED BY THE WIND CONDITIONS ACCOMPANYING THE FOG. IF THE WIND IS CALM THE BEST BURNER LOCATION IS NEAR THE RUNWAY. WHEN WIND IS BLOWING, THE BEST BURNER LOCATION IS UPWIND OF THE AREA TO BE CLEARED, THE DISTANCE UPWIND DEPENDING UPON THE WIND VELOCITY. SINCE BOTH OF THESE CONDITIONS OCCUR AT SAN FRANCISCO, THE FIDO DESIGN REPRESENTS A COMPROMISE IN WHICH LOCATION AND THERMAL OUTPUT HAVE BEEN ADJUSTED TO BE EFFECTIVE IN EITHER CONDITION WITHOUT EXCESSIVE FUEL EXPENDITURE, AND TO GIVE OPTIMUM CLEARANCE UNDER ALL CONDITIONS.

THE BURNER LINES ALONG THE LEFT (SOUTH) SIDE OF RUNWAY 28L ARE 400 FEET FROM CENTERLINE. THEY EXTEND FROM THE EDGE OF THE BAY, 1000 FEET BEYOND THE THRESHOLD OF THE RUNWAY, TO WITHIN 75 FEET OF THE TAXIWAY AT THE NORTHWEST END OF RUNWAY 28L (SEE THE DRAWING AT THE END OF THIS REPORT). THE MAXIMUM THERMAL OUTPUT RECOMMENDED IS 40 THERMS PER YARD-HOUR AT THE APPROACH END, DROPPING OFF TO A MAXIMUM OF 15 THERMS AT THE UPWIND END WHERE ONLY TAXIING CLEARANCE IS NEEDED. THIS BURNER LINE IS DIVIDED INTO 8 SECTIONS WHOSE LENGTH IS DICTATED BY CROSS TAXIWAYS AND RUNWAYS. NO SECTION COMES CLOSER THAN 75 FEET TO THE EDGE OF A TAXIWAY OR RUNWAY. THIS SHOULD BE AMPLE DISTANCE, SINCE THE BURNERS WILL BE USED ONLY FOR LANDINGS AND TAKEOFFS ON 28L, AND THERE SHOULD BE NO CROSS TRAFFIC AT THESE TIMES.

THE BURNER LINE ALONG THE RIGHT (NORTH) SIDE OF 28L EXTENDS FROM THE EDGE OF THE BAY UP TO, AND AROUND, THE UPWIND END OF THE RUNWAY. THE BURNER LINE OF THE RIGHT SIDE IS DIVIDED INTO 9 SECTIONS OF VARIABLE LENGTHS. THIS LINE IS 450 FEET FROM THE CENTERLINE.

The burners on either side of 28L are to be extended along the edge of the fill at the south of the runway and perpendicular to the centerline of the runway. Each approach end burner terminates 200 feet from the centerline, leaving a 400-foot gateway for landing planes. This is ample room for a pilot making an ILS or GCA approach. The turbulence over this gate 1000 feet from the end of the runway would not be excessive.

## Possible Future Extension

The lines on either side of 28L should be installed when the runway is built. If an additional length of clearance is desired in the approach zone, sections 1 and 2 (see drawing) can be extended out 1000 feet furthur into the approach zone over the bay. Such extended lines may be supported on piling and should be at runway level. It is not recommended that these lines be installed now.

When the traffic at the San Francisco International Airport becomes so heavy that Runway 28L cannot accommodate both arrivals and departures, a burner line (as shown on the drawing) should be installed on the right (north) side of 28R. Both 28L and 28R can then be cleared of fog by using either 2 or 3 burner lines.

## Equipment

It is recommended that a variable capacity system be utilized in the San Francisco fog dispersal installation. Each burner head should be a triad nozzle having a maximum capacity of 1.5 gallons per minute. The system should have a minimum thermal range of 2 to 1 to allow economical operation of the system in light fog with calm wind. The triad heads along a burner line should never be spaced more than 75 feet apart so that fog will not drift between them.

## Construction

The burner line should be laid level so that oil cannot dribble from the burner heads after the pressure is released. It is essential to leave the lines full of fuel at all times to assure immediate ignition when the time comes to light off; that is, when a plane is approximately 2 1/2 minutes out on the final approach. In this connection, also, a return gravity-feed by-pass to the storage should be provided around the high pressure pumps. Through the by-pass, the pressure can be exhausted and enough fuel withdrawn to drain the risers and halt combustion quickly at the end of a burn.

Two high pressure pumping stations are to be located on the right side of Runway 28L between the edge of the runway and the burner line (see drawing). These pumping stations are to be concrete vaults level with the ground and covered with material of sufficient strength to allow aircraft to cross them in case of emergency without damage to either the station or the plane. Provision must be made to keep the pits dry and well-ventilated. When the pits are constructed, space should be allowed for the further installation of additional pumps for the third burner line north of 28R.

A minimum storage capacity of 250,000 gallons is recommended. This storage will permit a minimum of 80 FIDO operations. However, before FIDO is installed, the speed with which additional fuel can be obtained should be determined; the storage capacity can then be adjusted accordingly. The storage area has been located on the edge of the field near the Coast Guard Air Station, with an alternate location not far from the threshold of 28L.

The burner groups are sectionalized by high pressure, hand-operated valves designed for adaption to remote control, if needed. (A hand-operated valve is, of course, much cheaper than any remote control type valve.) These valves will normally be in the open position. Should closure ever be necessary or desirable, there should be ample advance warning. All valves, other than these sectionalized valves, must be actuated through remote control.

All valves in the pump pit are to be remotely operated by the tower or FIDO operators, who will synchronize the burn with aircraft arrivals and departures.

The high pressure burner line should be fabricated of seamless steel tubing. Tubing is only slightly more expensive than high pressure pipe, and will give longer, more satisfactory service.

The pumps should be capable of delivering 250 gallons of fuel per minute at 1200 to 1500 pounds per square inch. They should be driven by electric motors. The circuit should be designed so that one motor gets up to speed before the next can be started. This will reduce the power demand to less than half, and in turn reduce the power cost. Six 250 gallon per minute pumps are needed to supply the installation at maximum output. A seventh pump should be added as a standby.

The ignition system of the fog dispersal system is to be automatic. An electrical ignition system is preferred, in which either a hot wire coil or a calrod unit is used.

A LOW PRESSURE PUMPING STATION WILL BE NECESSARY NEAR THE STORAGE AREA. THIS PUMPING STATION MUST BE CAPABLE OF FURNISHING 1500 GALLONS OF FUEL PER MINUTE, 75 POUNDS PER SQUARE INCH, TO THE HIGH PRESSURE PUMPING STATION. LOW PRESSURE SUPPLY PIPE CAN BE USED FROM THE STORAGE AREA TO THE HIGH PRESSURE PUMP STATION. A SUITABLE SYSTEM OF CHECK VALVES IS MANDATORY.

## WEATHER MEASURING INSTRUMENTS

IT IS RECOMMENDED THAT TRANSMISSOMETERS WITH 500 FOOT BASELINES BE INSTALLED FOR MEASURING CLEARANCE ACTIVITY. ONE SHOULD BE NEAR THE EDGE OF THE BAY INSIDE THE APPROACH BURNERS, AND THE SECOND ALONGSIDE THE MIDDLE OF THE RUNWAY, ALSO INSIDE THE BURNERS. THESE INSTRUMENTS WILL GIVE CONSTANT RECORDS OF THE VISIBILITIES IN THESE AREAS. NO PART OF THE TRANSMISSOMETER BASE LINE SHOULD BE CLOSER THAN 100 FEET FROM ANY BURNER LINE, SINCE THE HEAT SHIMMER NEAR THE BURNER HEADS WOULD GIVE AN ERRONEOUS READING. A CEILOMETER SHOULD BE INSTALLED ON A 500-FOOT BASE LINE ALONG THE EXTENDED CENTERLINE AT THE MIDDLE OF THE FILL. THE 500-FOOT BASE LINE DEPARTS FROM NORMAL WEATHER BUREAU PRACTICE; BUT ACCURACY IN THE MEASUREMENT OF LOW CEILINGS CANNOT BE OBTAINED ANY OTHER WAY. THE DETECTOR MECHANISM SHOULD BE ALTERED TO LIMIT THE SCANNING CYCLE TO THE LOWEST 500-FOOT SECTION OF THE PROJECTOR BEAM, SINCE THIS IS THE REGION OF PRIMARY INTEREST IN LOW CEILING OPERATIONS. ALSO, THE SHORTER SCAN WITH A MODIFIED RECORDER WILL ALLOW MORE FREQUENT INSPECTION OF THE CRITICAL AREA, WHICH IS ESSENTIAL TO ECONOMICAL USE OF FIDO

## Training Program

After FIDO is constructed, it will be necessary to train ground personnel thoroughly in its use and maintenance if economical operation is to be obtained. An operations and maintenance manual should be developed. Careful operational records kept and analyzed periodically to insure that operating techniques are efficient and economical. We suggest that a series of practice operations be conducted at intervals in which pilots can simulate instrument approaches and become acquainted with San Francisco's FIDO. Movie records should be made during these practice periods, both on the ground and from the air, and these films should be shown, either at the terminal or through distribution to the airlines, to all pilots likely to use FIDO. As soon as fog occurs, the appearance of FIDO in low visibility conditions, both day and night, should be filmed for training purposes.

SECTION 7.

# LAYOUT OF INSTALLATIONS

THE PLAN SHOWS INTERIM AND FINAL LOCATIONS OF LANDING AIDS RECOMMENDED FOR THE SAN FRANCISCO INTERNATIONAL AIRPORT. THE AIDS AND THEIR LOCATIONS HAVE BEEN CHOSEN WITH THE AIM OF PROVIDING MAXIMUM UTILITY AT A MINIMUM EXPENSE FOR INSTALLATION AND MAINTENANCE.

AVIATION FACILITIES ASSOCIATES
ARCATA , CALIFORNIA

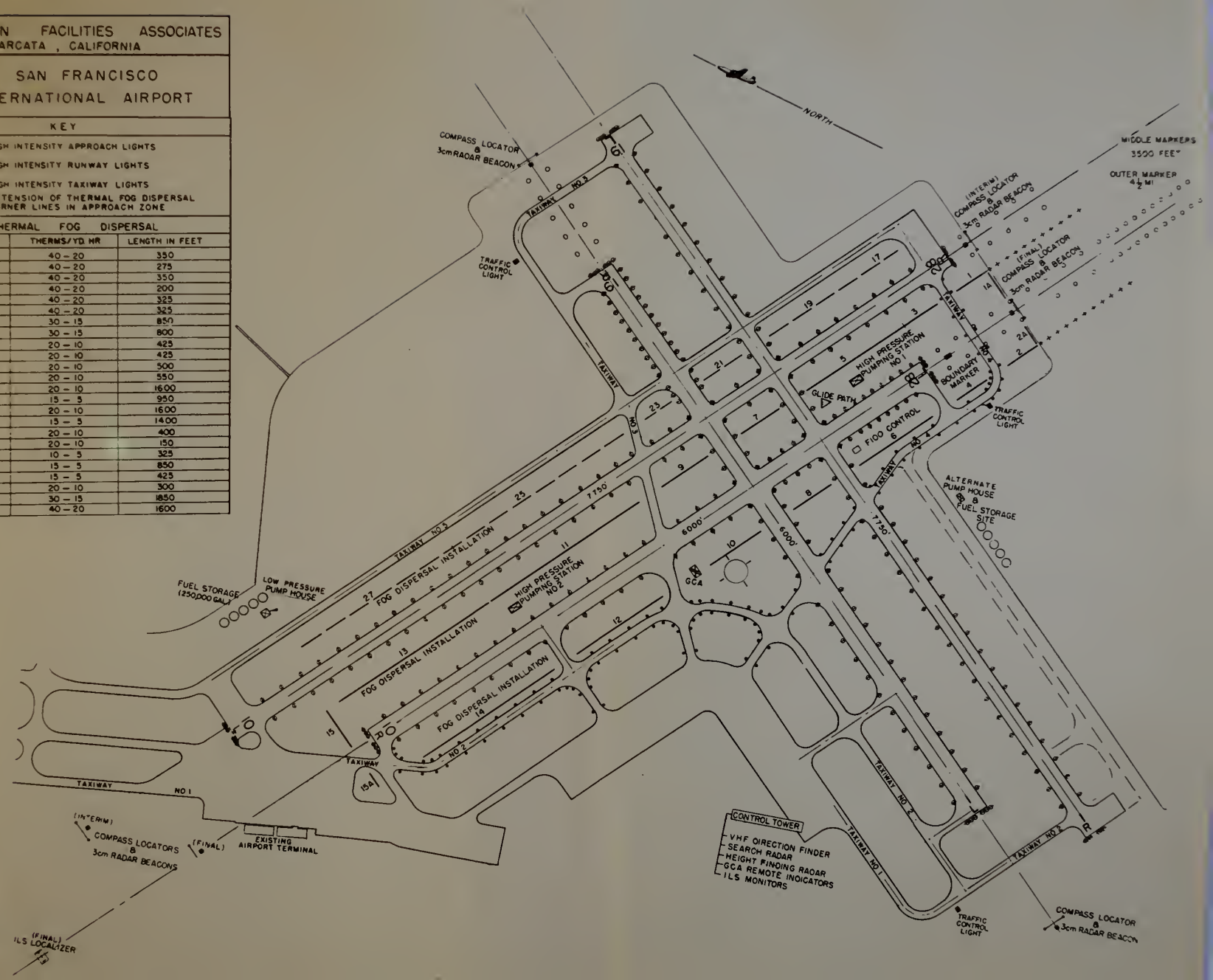
# SAN FRANCISCO INTERNATIONAL AIRPORT

KEY

- ○ — HIGH INTENSITY APPROACH LIGHTS
- ⊖ — HIGH INTENSITY RUNWAY LIGHTS
- ● — HIGH INTENSITY TAXIWAY LIGHTS
- \+ — EXTENSION OF THERMAL FOG DISPERSAL BURNER LINES IN APPROACH ZONE

THERMAL FOG DISPERSAL

| SECTION NO | THERMS/YD HR | LENGTH IN FEET |
|---|---|---|
| 1 | 40 – 20 | 350 |
| 1A | 40 – 20 | 275 |
| 2 | 40 – 20 | 350 |
| 2A | 40 – 20 | 200 |
| 3 | 40 – 20 | 325 |
| 4 | 40 – 20 | 325 |
| 5 | 30 – 15 | 850 |
| 6 | 30 – 15 | 800 |
| 7 | 20 – 10 | 425 |
| 8 | 20 – 10 | 425 |
| 9 | 20 – 10 | 500 |
| 10 | 20 – 10 | 550 |
| 11 | 20 – 10 | 1600 |
| 12 | 15 – 5 | 950 |
| 13 | 20 – 10 | 1600 |
| 14 | 15 – 5 | 1400 |
| 15 | 20 – 10 | 400 |
| 15A | 20 – 10 | 150 |
| 17 | 10 – 5 | 325 |
| 19 | 15 – 5 | 850 |
| 21 | 15 – 5 | 425 |
| 23 | 20 – 10 | 300 |
| 25 | 30 – 15 | 1850 |
| 27 | 40 – 20 | 1600 |



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